

# **INNOVATION PATHWAYS IN THE CHINESE ECONOMY**

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# INNOVATION PATHWAYS IN THE CHINESE ECONOMY

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## LIST OF SYMBOLS AND ABBREVIATIONS

3GPP	3rd Generation Partnership Project
CAS	Chinese Academy of Sciences
CCP	Chinese Communist Party
DRAM	Dynamic Random-Access Memory
ESOP	Employee Stock Ownership Plan
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GPN	Global Production Network
GVC	Global Value Chain
IC	Integrated Circuit
ICT	Information & Communication Technology
IDM	Integrated Device Manufacturer
IPO	Initial Public Offering
IPR	Intellectual Property Rights
JV	Joint Venture
LSI	Large Scale Integration
LTE	Long Term Evolution
MEI	Ministry of Electronics Industry
MNC	Multinational Corporation
NIE	Newly Industrialized Economy
NIS	National Innovation Systems
OBM	Original Brand Manufacturing
ODM	Original Device Manufacturing
OECD	The Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturing
PAT	packaging, assembly, and testing
PBX	private branch exchange
PDSS	Public Digital Switching Systems
PLA	People's Liberation Army
R&D	Research & Development
RAM	random access memory
RAN	Radio Access Network
S&T	Science & Technology
SASAC	State-owned Assets Supervision and Administration Commission of the State Council
SDR	Software Defined Radio
SMIC	Semiconductor Manufacturing International Corporation
SOE	State-owned Enterprise



TD-SCDMA	Time Division-Synchronous Code Division Multiple Access
TMFT	Trade Market for Technology
TSMC	Taiwan Semiconductor Manufacturing Corporation
USPTO	United States Patent and Trademark Office
WAPI	WLAN Authentication and Privacy Infrastructure
WCDMA	Wideband Code Division Multiple Access
WFOE	Wholly Foreign Owned Enterprise
WIPO	World Intellectual Property Organization

## SUMMARY

This study investigates emerging innovation pathways in the Chinese economy. An innovation pathway is defined as the historical and evolutionary process through which business firms establish and accumulate capabilities in technology development and market access that enables them to compete with international technology and market leaders. The study proposes a framework for understanding the development of innovation capabilities through the interactions of institutional forces of state, market, and globalization. The main proposition is that innovation pathways in China emerge when the government policy synchronizes with domestic market development and global industry evolution in providing opportunities, resources, and a broad set of complementary capabilities necessary for technology development. Conversely, where public policy is out of step or asynchronous with global industry and domestic market institutions, this delays or inhibits the emergence of innovation pathways. Searching for synchronization requires the co-evolution of government policy and business strategy.

The framework and theory is used to explore case studies of leading Chinese firms in two critical information technology industries: the telecom equipment industry and the semiconductor industry. In the semiconductor industry, leading Chinese firms struggled to close technological gaps with international leaders. This was because state-led development was out of step with global industry evolution while business-led development was decoupled from domestic markets. In comparison, in the telecom equipment industry, innovative indigenous companies emerged from a synchronization of public research, government investment in infrastructure, multi-layer domestic markets, and accessible global suppliers in the 1990s. The exceptional case of Huawei Technologies Co., the Chinese telecom equipment maker that has become an international

innovation leader, shows how innovative Chinese firms capitalize on and complement government policies by strengthening internal R&D and aggressive internationalization.

This study contributes to economic theories on how firms from emerging economies can learn to innovate. Traditional views emphasize transferring technologies from advanced economies, following a learning sequence of reverse product cycles, and more recently, specializing in manufacturing in the global value chains. This study offers an alternative view that in today's advanced industrial and globalized world, emerging economy firms can succeed in innovation by exceling in new technology development and market access capabilities, provided that government policy synchronizes with domestic market and global industry conditions to offer a broad range of complementary capabilities.

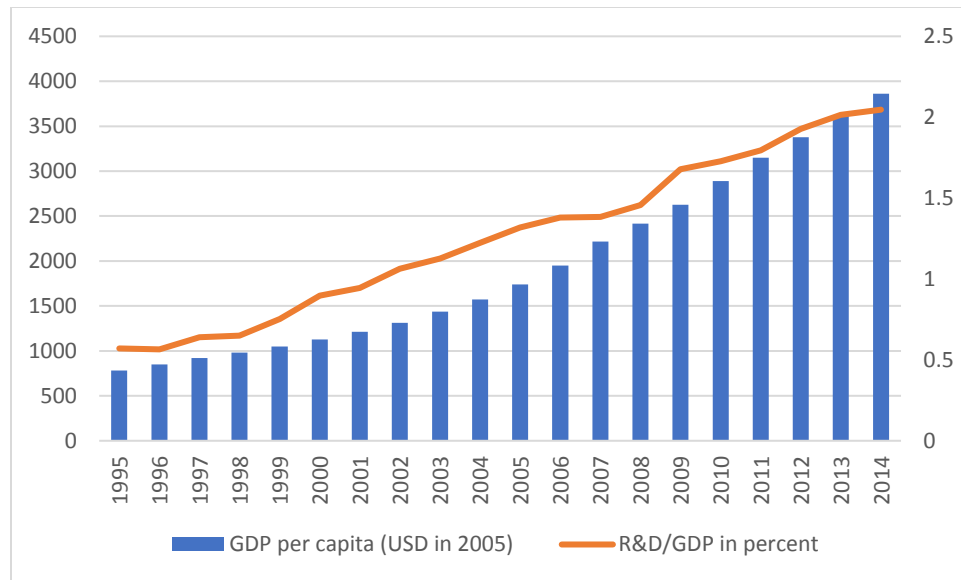
# CHAPTER 1. INTRODUCTION

## 1.1 Background

This study investigates the emergence of innovative Chinese companies and the pathways through which innovation occurs in China. By innovative firms, I mean companies that advance technological frontiers by transforming new scientific and technological progresses into commercially successful goods and services. As China is an emerging economy, innovative firms have to push China's technological frontiers first before they emerge as leaders on the global markets. Consequently, this study focuses on the pathways of innovation, that is, the historical and evolutionary process through which companies accumulate capabilities in technology development and market access that enables them to compete in terms of quality and cost with international leaders.

The background to this study is China's meteoric rise in economic development and the emergence of its innovation power. Since the late 1970s, three decades of high-speed economic growth have transformed China from an impoverished state-planned socialist society into one of the most dynamic capitalist economies and the world's second largest economy. With the economy booming, the Chinese government has stated the goals for China's next stage of development are to become an "innovative nation" by 2020 (Li 2012). As formulated in the Medium- and Long-Term Plan for Science and Technology in 2006, central to the government planning is a strategy of *Zizhu Chuangxin* (自主创新), translated as "indigenous innovation". The "indigenous innovation" strategy stresses the accumulation of capabilities by the Chinese government and domestic business that gives them greater control over and mastery of the innovation process.

Today, there is growing evidence that innovation is occurring in China at various levels. At the national level, China has an impressive record of investing in and generating results from innovation activities. On the input side, China has made massive commitments to research and development (R&D) spending and invests heavily in human capital for R&D. In terms of R&D spending, China has spent more on R&D than other countries with similar levels of GDP per capita. According to OECD data (Figure 1), in 1991, the earliest year with data available, China invested 0.7 percent of GDP in R&D, a level of intensity on par with major developing economies such as India, Brazil, or South Africa, but much lower than innovation leaders like United States, Japan or Germany. By 2012, China's R&D spending had caught up with OECD average (at 1.88 percent of GDP). By 2014, its R&D spending had reached 2.05 percent of GDP, even though China's income level was still only one fifth of the OECD average. In terms of investment in human resources, the share of researchers in the population grows steadily. From 1996 to 2014, the ratio of researchers in China had grown from 443 to 1,113 researchers per million population. In comparison, the share for high income countries is 3,985 per million in 2012, but the Chinese ratio in 2014 is comparable to upper middle-income countries (1,266 per million in the same year) (Wei et al 2017, p.58-59). As the result of R&D spending expanding faster than the number of researchers, Chinese researchers not only have one of the largest R&D budgets in aggregate but R&D expenditure per researcher has grown as well.



**Figure 1 Growth of income and R&D intensity in China, 1995 - 2014**

*Source: OECD database (<https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm>)*

In terms of innovation output, one common measure is the number of patents. The number of Chinese patents has experienced explosive growth in recent years. Data from China's State Intellectual Property Office (SIPO) shows, from 1995 to 2014, the number of domestic patent applications filed has grown from 83,045 to 2.3 million, recording a growth rate of nearly 20 percent every year. China overtook the United States as the country with the most number of patent filings and grants in the world in 2011 and 2016, respectively. If the sheer number of patents filled with Chinese authorities might raise the concerns about quality, one can double check the quality of Chinese patents by examining patents of Chinese entities in advanced countries with high patenting standards. The number of patents by the U.S. Patent and Trademark Office (USPTO) to Chinese firms increased from 62 in 1995 to 7,236 in 2014, at annual growth rate of 26 percent. In comparison, China still falls behind international innovation leaders, such as Japan, Germany, or South Korea, each having 53,849, 16,550, and 16,469 patents granted by USPTO in 2014. But

China is far ahead of any other large emerging economy, including India (2,987), Brazil (334), Russia (445), and South Africa (152) (Wei et al 2017, p.60 - 63).

At the industry and corporate levels, a range of Chinese industries and their leading companies are rapidly approaching or already advancing international technology frontiers. China has achieved most success in the broad information and communication technology (ICT) industries where it generates a growing number of innovative companies, including the telecom equipment maker Huawei, the civilian drone maker DJI, Internet technology giants Baidu, Alibaba, and Tencent that have emerged as technology and market leaders (Economist 2015a, b, McKinsey&Company 2015, Osawa, Wong and Carew 2014, Sampere 2014, Tse 2015). Among them, Huawei and ZTE have occupied the positions as the companies with the largest number of patent applications and grants with the World Intellectual Property Organization (WIPO) since the mid-2000s. More recently, Chinese companies are establishing themselves as top investors in corporate R&D. In 2016, Huawei invested over US\$10 billion in R&D activities, which would put the company among the global top ten corporate R&D spenders for the first time if Huawei were a public company (Huawei 2016, PriceWaterhouseCoopers 2017).

China's emerging innovation power is not limited to the ICT industries. It has already successfully created the world's largest industry in high-speed rail, solar panel and wind turbine. Over the last decade, China has made inroads into semiconductor fabrication and is increasingly threatening US technological dominance in this backbone industry of information technology (PCAST 2017). Most recently, China has been credited as an international leader in several emerging technology areas, including high-performance computing, quantum communication, and artificial intelligence (Wang 2017).

China's advances in technology and innovation are less impressive, however, considering its continental-sized economy and the world's largest population. On a per capita basis, China's R&D input and output, while ahead of other large developing economies, are still fall behind the leading innovation nations (Wei et al 2017). Even though a few star Chinese companies in selected high-tech industries have achieved the status of world leaders in innovation, the majority of the Chinese economy is far away from the leading edges (Zhou, Lazonick & Sun 2016). For example, being the world's largest automobile market, China has yet to generate any significant car makers in terms of technology leaders or world market shares. The contradiction in China is, that the country is a top performer in aggregate R&D at the same time of being relatively low performer on per capita basis, and it has both star companies and lagging industries. This reveals a high-degree of unequal development among China's advanced sectors and regions and the rest of the country. It also raised an overarching question: How did the most advanced sectors and companies get so advanced so quickly?

## **1.2 Motivations**

How Chinese companies became innovative, however, has been profoundly misunderstood in both the West and the East. In the East, China is often assumed to have simply followed footsteps of an export-driven growth strategy well established by the neighboring East Asia nations. Studies of East Asia's newly industrialized economies (NIEs) after the World War II have attributed their economic success to a combination of factors, including borrowing and learning technologies developed elsewhere, developmental government policies and an export-driven growth strategy. Because of the nature of late industrialization in the NIEs, technological development is carried



through learning or borrowing from advanced economies, and the most effective way to learn is through exports under the guidance and assistance of multinational corporations (MNCs) involved in the production for the advanced markets (Amsden 1989, Wade 1992). In South Korea, technological learning is undertaken through a combination of technology licensing, imitation of industry leaders and local experiments by large business groups, or *chaebols*, which possess the necessary scale and capital to bear the risks of transitioning from low- to high-technology industries. In smaller open economies, such as Taiwan and Hong Kong, subcontracting linkages to MNCs are instrumental in providing technological training to local firms. In general, NIE firms started from mature, standardized manufacturing products and processes, then traveled backward along the product life cycle, and incrementally accumulated technical, management and marketing capabilities. Eventually, a small number of the NIE firms may acquire the necessary design, R&D, manufacturing, and marketing competences on a par with the Japanese and Western firms (Amsden, 1992, 2001; Enos, Lall and Yun, 1997; Hikino and Amsden, 1994; Kim, 1995, 1997; Hobday, 1995a, b; Lall, 2000; Mathews and Cho, 2000). The export-driven growth strategy in NIEs is so successful that in the mid-1990s, the World Bank advocated export promotion as a proven economic development policy (World Bank 1993).

Even though China has achieved enormous successes in the export markets and shares substantial cultural and societal similarities with the NIEs, there are enormous barriers for China to replicate the experiences of NIEs when it comes to technology development. One barrier is China's geopolitical position. Unlike the post-war Japan, South Korea, Taiwan and Singapore, which are all American allies, China is ruled by a Communist Party and stands as a geopolitical rival to the United States in East Asia. Unsurprisingly, China faces much stricter restrictions in technological acquisitions from the developed West. The United States has longstanding rules and

regulations prohibiting Western companies from exporting a wide range of military-civilian dual-use advanced technologies to China, including high-performance computers and semiconductor fabrication machinery (See GAO 2002). Such rules would not be applied to South Korea or Taiwan, which relied heavily on imported capital goods in the initial stage of building up their high-tech semiconductor industries (Mathews and Cho 2000). This affects not only business, but also it limits how Chinese public research institutions with close linkages to the CCP can function as intermediaries in purchasing, assimilating, and diffusing foreign technologies (Zhou 2008).

The other barrier for China to copy the NIE model is the size of its economy. China's accession into the World Trade Organization (WTO) in 2001 has integrated hundreds of millions of low-wage Chinese workers into global production, and there is growing evidence that trade with China has caused widespread and negative impacts on the US labor markets (Autor et al 2013, Acemoglu et al 2016). The job losses and wage depressions in Western economies have led to political backlash towards Chinese exports. Already being the world's largest exporter, it is unlikely that Chinese companies can continue to upgrade capabilities and capture higher-value-added activities by relying solely on exporting without being countered by Western governments and companies.

But unlike the smaller East Asian NIEs, China has the advantage of a large and dynamic domestic market. According to the estimation by economists Brant and Thun (2016), up to 85% of all industrial products manufactured in China, which is the world's largest industrial producer, are sold domestically. China currently has the world's largest market in terms of both absolute size and growth rate, in a wide range of sectors extending from steel to automobiles to cell phones to semiconductors and to machine tools. Studies of export-driven growth in NIEs might have ignored the roles of domestic markets for legitimate reasons, because the size of their domestic markets

are neither big enough to support sufficient scale in industries nor significant in comparison to potential export markets. However, the impact of a vast and growing market as China's on any economic process can hardly be omitted. Here, lessons from the experience of earlier industrializers could be more instructive than the NIEs. Among today's developed economies, the United States, Germany, and many other Western European nations, had all historically exploited their domestic markets through tariff protection and subsidies to jump start industrialization (Chang 2002, Gordon 2004). Of course, it is impossible for contemporary developing nations to use a similar protectionist strategy in a globalized world. And I am not advocating such policies, either, since state protectionism has led to major failures as it was practiced by China, India, and Brazil in the 1950s and 60s. In fact, as economists have pointed out, the Chinese market after the accession to the WTO in 2001 has already become one of the most open markets among large countries, and certainly more open than Japan or South Korea in their economic boom years of the 1970s and 80s (Naughton and Segal 2003, Brant and Thun 2010). The point is, the existence of a large and dynamic domestic market presents a unique opportunity structure for Chinese companies to engage in technological learning and innovation. Other than learning through exporting, Chinese firms can grow through understanding the domestic market, developing capabilities to capture opportunities emerging at home, and engaging in the process of combining and recombining inputs and creating productive capacity to meet the market demand. Such a process is generally considered as innovation (Schumpeter 1934; OECD 2005).

In the West, China has been viewed as a prime example of state capitalism, an alternative economic order that challenges the liberal capitalist economy. There have been heated debates

about the rise of state capitalism with scholars in defining the term in varying ways<sup>1</sup>, but the most common view is that state capitalism entails extensive control of the economy by the state through direct ownership in state-owned enterprises (SOEs) or indirect ownership of publicly traded companies with state institutions as shareholders (Bremmer 2009). Under state capitalism, the government uses tools of industrial policy for “picking winners”, establishing firms with government funding, giving favors to selected business, most likely SOEs, and promoting them to become National Champions in participating in international competition.

The state capitalism view of China has overlooked the sheer size of China’s non-state sector and its dynamism. Data from China Firm Registry shows that since the mid-1990s, both the absolute number and the share of state-owned firms in the Chinese corporate sector has been declining. In 1995, state-owned companies accounted for 24 percent of total firms in China, but by 2014, their share was merely 3 percent. The large drop in the number of state-owned enterprises resulted from a gradual privatization policy called “Zhua Da Fang Xiao” (literally means “keeping the large (firms), releasing the smaller ones”) since the late 1990s, which involves privatizing smaller state-owned enterprises and consolidating the larger ones. During the period of 1995-2014, the number of non-state firms, including private companies and firms with mixed ownership, registered an annual growth rate of 9 percent, reflecting vibrant entrepreneurship and new firm creations. The growth rate of non-state firm is an even more impressive 11 percent during the later period of 2005 – 2014. By 2014, there were 16.9 million non-state firms comprising 94% of all firms operating in China (Wei et al 2017, p.52).

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<sup>1</sup> See discussions on “The Rise of State Capitalism,” *The Economist*, Jan. 21, 2012 < <http://www.economist.com/node/21543160> >. For a rebuttal of China’s state capitalism, see Lardy (2014) and Malesky & London (2014).

Even if there is certain truth in the state capitalism view of China, the current debates miss the point when it comes to understanding the dynamics of innovation. Recent studies on a broad range of Chinese industrial sectors have revealed that the Chinese state is far from the overarching Leviathan image envisioned in the West (Zhou, Lazonick and Sun, 2016). It is true that, the Chinese state has indeed maintained a consistent goal of obtaining technological self-sufficiency and reducing dependency from the West, but its policy and practices have evolved over the years. In the 1980s and 1990s, China practiced a form of state capitalism through industrial policies to create national champions from SOEs and trade market access for the transfer of foreign technologies, in the hope that the Chinese SOEs would progress from mastering production technique to innovating based on absorbed technologies. Such policies, often called “Trade Market for Technology” (TMFT), were practiced in a broad range of industries from automobile to telecom equipment to semiconductor fabrication that had been considered as strategic industries by the state. These efforts have built a massive array of manufacturing capabilities in China, especially in mature industries, such as steel, chemical, and automobile industries, where state-owned firms with scale and power are occupying the commanding heights of the traditional industrial economy. But the state industry has been far less successful in emerging and dynamic industries. Nor are these state-sponsored champions responsive to rapid technological changes. In recent years, while the roles of the Chinese state are still extensive and multifaceted, the state has become flexible and collaborative in responding to the needs of the business enterprises, many of them being non-state. One of the few exceptions in China’s state capitalism practice is perhaps the success of China Railway Corporation (formerly Ministry of Railway) in building the high-speed rail industry. But the conditions in this particular sector, namely the need for national central planning, enormous capital requirements, and a closed market controlled by government

procurement, is so idiosyncratic that its lesson of state capitalism can hardly be generalized anywhere else (Liu, Lv and Huang 2016). In short, none of the Chinese SOEs cultivated by state capitalism has emerged as innovative in globally competitive industries (See, Huang 2008, Breznitz and Murphree 2011, Zhou, Lazonick and Sun, 2016).

The leading innovative Chinese companies have consistently been non-state companies, even though government policies favored the state-owned sectors. Since the mid-1980s, newly created, non-state companies have spearheaded China's entries in its emerging ICT industries. In the 1980s and 1990s, the leading Chinese S&T firms were the so-called *minying* (民营, translated as "people-run" as opposed to state-run) companies, China's first-generation for-profit commercial enterprises, most of which had private ownership but many were backed by state institutions as major shareholders (Lu 2000). Since the 2000s, the newer generation of non-state firms has been increasingly internationalized, many with entrepreneurs and management teams with both Chinese market knowledge and international experience and backed by capital from a variety of state, domestic private, and international sources (Zhou 2008; Li 2016). In the process of China's entry into PC, telecom equipment, smartphone, semiconductor, IC design and various high-tech sectors, these non-state firms have subsequently grown into the most successful and innovative firms in their respective markets. Among them, well-known examples include personal computer manufacturer Lenovo, telecom equipment makers Huawei and ZTE, civilian drone maker DJI, Internet technology giants Baidu, Alibaba, and Tencent.

It might seem to be a paradox that the Chinese government favors the state industry in industrial and innovation policy, but the most innovative Chinese firms are not state-owned. Scholars have confronted the issue of private industry development from various angles: some point to the role of local governments in cultivating and protecting local private businesses (Shirk

1993; Huang 1996; Oi 1999; Segal 2003), others have suggested that private business in China thrived through exploiting domestic and exporting markets without much government assistance (Gadiesh, Leung, & Vestring 2007; Zeng & Williamson 2007), and most recently, it has been argued that the roles of the Chinese state have evolved towards being more flexible and responsive in catering to business needs (Zhou & Liu 2016). In a recent collection of studies of nine industrial sectors in China, ranging from automobile to machine tools to ICT to renewable energy, the authors look at the evolution of these industries and they have not found a single pattern of innovation: in some sectors, government assistance appears important (e.g. wind turbine), while in others, innovative private firms grew through exporting (e.g. solar photovoltaic) (Zhou, Lazonick & Sun 2016). The multi-industry study highlights the complexity in the Chinese context of industrial development, where government policy varies by sectors and interacts with specific technological and market conditions in the industry to influence the behaviors of state-owned and private firms. The bottom line is that there might be more than a single answer to the paradox of ‘unexpected successes’ of Chinese non-state firms. To understand their innovation success, one needs to study the industry and companies in context.

In short, the process of building innovative capabilities of indigenous companies in China differs from the experience of leading companies in previous East Asia NIEs. It is safe to say that some Chinese companies might indeed have followed the footsteps of earlier NIEs by being subcontractors to MNCs and climbing up the technological ladders through exporting. The Chinese state might also be able to prop up a few national champions in selected industries when market and technological conditions favored state ownerships. However, a majority of Chinese companies, especially the non-state companies that are leading Chinese innovations, would find their pathways to innovation shaped by forces such as expanding domestic markets, extensive globalization at

home, and changing roles of the state. Thus, their paths to innovation are vastly different from those of companies in previous industrializers.

### **1.3 Task of This Thesis**

In this study, I embark on a task to understand the innovation pathways of Chinese companies, especially in the ICT industries where China has obtained most success so far. Central to this task is to construct a theory of how innovation occurs in a socioeconomic environment that is different from previous experience of advanced economies or other newly industrialized economies. The innovation environment in China entails a combination of conditions that has never been seen before, as it is characterized as a large emerging economy with private business development, expanding markets, an open economy, and changing roles of the government. To understand the Chinese innovation process thus is a difficult task, and it is best done through an explorative study drawing on the experience of successful cases. That being said, such understanding would have extra values in not only better understanding and assessment of Chinese innovation, but expanding the theory of innovation in uncharted realms.

Specifically, this study is motivated by the following questions:

- What is the state and potential of innovation by Chinese companies in the leading industrial sectors?
- How have Chinese companies become innovative and how have their innovation pathways differed from those of advanced or other newly industrialized nations?
- What are the key institutions and social conditions that underpin the Chinese innovation pathways?



The dissertation is organized in six chapters. Chapter 2 Theoretical Framework starts from an overview of three theoretical traditions of innovation studies, especially from the perspective of emerging economies, then insights from theories are used to engage in the debates of the status of Chinese innovation and highlight the (mis)understandings in the recent literature. It is followed by a framework and research design that lays out the main arguments and a structure for exploring case studies. The framework's analytical lens focuses on the process of developing innovative capabilities at the firm level, with attentions to the co-evolution of government policy, market demand, and technology development that underpin the firm-level process. The framework is followed by the research design of empirical cases studies following the institution-industry studies tradition, with the explanations of case selection and data collections.

Chapter 3 gives a country-level overview of innovation activities in the Chinese context, focusing on the impacts of the three institutional forces of state, market, and globalization on the process of developing innovation capabilities in China. Chapter 4 and 5 document and analyze the cases of Chinese companies and their innovation pathways in the semiconductor fabrication and telecom equipment industries, respectively. Chapter 4 traces the history of developing the semiconductor industry in China since the 1980s, examining the subsequent emergence of leading firms with varying business structures under changing government policies. Chapter 5 focuses on a single firm, Huawei, which has led technological development since the 1990s, but the chapter also dives deeper into the processes of major technical innovations at Huawei. Finally, Chapter 6 summarized findings in case studies to propose a theory of innovation pathways in China, and engages in current literature once more to contribute to the understanding of how innovation occurs in emerging economies.

## **CHAPTER 2. THEORETICAL FRAMEWORK AND RESEARCH DESIGN**

### **2.1 Chapter Introduction**

In this study, I consider innovation as the process in which firm invent, learn, and profit from processes of production and distribution of goods and services new to the national economy. As such, innovation is more than mere invention or technological change, as innovation also includes the process of introducing new methods and organizational forms in the marketplace (OECD 2005, p. 146).

The study of innovation as sources of economic growth is a long-standing interest. Smith (1776) wrote in *Wealth of Nations* about the division of labor as a source of wealth creation, while for Marx (1867), technological change in the form of replacing skills with machines was a key driver in capitalist economic and societal development. In *The Theory of Economic Development*, Schumpeter (1934) laid out the modern conception of innovation as an economic process in which entrepreneurs and firms transform new ideas, products and processes into economic outcomes, creating new markets and industries and destroying old ones – a process of “creative destruction” that is central to the dynamism in a capitalist economic system.

In light of the strong links between innovation and the economic prosperity of a country, academic debates have argued about the sources, nature, and impacts of innovation and the roles and limitations of government and public policies in encouraging innovation in the domestic economy. Several strands in the innovation literature offer keys to answers to the overarching questions in this study: How technological change and innovation occur in societies other than

mature capitalist economies? How firms and industries in one large and open emerging economy like China move to the technological frontier and become innovative? In the following section, I review established views on the nature and source of innovation and the roles of state policies and institutions in the innovation process in three strands of literature: The first view is the Product Cycle and related stage models, which view the development of production and technological capabilities at emerging and developing economies as the results of diffusions of mature technologies from developed nations (Akamatsu 1962; Vernon 1966; Vernon 1979; Cumings 1984). The second view is grounded in a set of system models, particularly National Systems of Innovation, that situate the occurrence of innovation in a myriad of dense relationships with external actors, organizations and institutional arrangements (Archibugi et al. 1999; Carlsson et al. 2002; Carlsson and Stankiewicz 1991; Edquist 2010; Freeman 1987; Lundvall 2007; Lundvall 2009; Nelson 1993). The third view is the learning models, especially models drawn on the experience of East Asia development, that see the development of innovation capabilities as resulting from government policy and firm learning (Johnson 1982; Amsden, 1992, 2001; Enos, Lall and Yun, 1997; Hikino and Amsden, 1994; Kim, 1995, 1997; Hobday, 1995; Lall, 2000; Mathews and Cho, 2000).

Building on the insights from classic innovation literature, I will engage in current debates on the nature and characteristics of innovation in China. From there, I present a framework for this study and research method and data.

## 2.2 Theories of Innovation: A Literature Review

### 2.2.1 *Product Cycle and Stage Models*

One of the oldest and most established views, grounded in Vernon's 1966 paper on Product Life Cycle, perceives an international division of labor on innovation and industry activities among advanced and developing economies (Akamatsu 1962, Vernon 1966, Vernon 1979, Cumings 1984). Vernon (1966) defines product life cycle or product cycle, as a new product progresses through a life cycle comprised by stages of introduction, growth, maturity and decline.

According to the Product Cycle theorists, innovation is an exclusive domain for the firms in the advanced economy. Advanced economies not only host firms with the necessary technological capabilities and managerial skills to overcome the challenges in innovation and commercialization at technology frontiers, but they also provide firms with a lead market with sophisticated buyers who have high levels of disposable income to afford the high prices of new technologies. In the Product Cycle model, innovative firms often have to co-locate the functionalities of R&D, manufacturing, and marketing with close geographical proximity to the lead market to make iterative product design changes and solve problems in manufacturing scale-up in the early stage of product development. Once the industry moves towards a later stage in the Product Cycle – when the product design is standardized, manufacturing process is matured, and increased competition has depleted innovators' profits – the production will be shifted to developing economies with lower technological capabilities and less affluent markets.

While Vernon's original model predicted a simple division of labor internationally, theorists in this perspective extended the basic model in many directions. Recently, theorists have been aware that the traditional Product Cycle models are “static” in sense that positions of

countries in the division of labor are set. Thus, more “dynamic” versions of the Product Cycle have been introduced, in which developing economies upgrade through receiving matured technologies continuously, while advanced economies innovate continuously to maintain their positions in the international division of labor (Krugman 1979, Grossman and Helpman 1991). Yet these extensions of Product Cycle leave the basic conclusions unchanged, that is a division between advanced and developing economies in occupying emerging and mature industries.

Since the 1980s, the last wave of globalization has fundamentally changed the organization of global industry, and assumptions of the Product Cycle no longer hold in the new environment. In this globalized world, trade liberalization, advances in information and communication technologies (ICT), and a process of modularization – the standardization of interfaces between components – enabled the production process in many industries to be highly fragmented. That is, the design, manufacturing, transportation of one product is increasingly distributed among different firms across borders at different stages of production. The direct consequence of production fragmentation is that firms in advanced economies no longer need to keep manufacturing in close proximity with other functions and the market. But instead, those firms can pursue an outsourcing and offshoring strategy to move the low-skill, low value-added manufacturing activities to low cost locations even in early stage of product development (Baldwin and Clark 2000; Berger 2005; Camuffo 2004; Ge and Fujimoto 2004; Gereffi et al. 2005; Langlois 2002; Steinfeld 2004; Sturgeon 2002).

While Vernon’s model of international distribution of emerging and mature industries might not apply to many industries in this new order, his broad idea of an international division of innovation and industry labor appears to hold. Recent literature on global production systems shares the view that innovation is a privilege for firms in the advanced economies. Unless firms

from developing economy can emulate the capabilities of advanced economy firms in technology development and market access, they will not be able to participate in new product development and high-value activities but will be stuck in the mature, standardized, and low-value parts of the value chains. Literature in the Product Cycle tradition, unfortunately, has not offered much guidance on how developing economy firms might acquire such capabilities. There is no explicit role of the government or public policy in the process of the diffusion of innovation throughout product cycle, which is primarily driven by the multinational corporations to standardize production process and lower skill requirements to adopt for developing countries.

### *2.2.2 System Models*

A second view on innovation perceives that innovation occurs within an eco-system involving both the innovating firm and a set of external actors, organizations and relationships that is often deeply embedded in the national context. This view can be broadly labeled as “system models”, and is well established by literature in National Systems of Innovation (Archibugi et al. 1999; Carlsson et al. 2002; Carlsson and Stankiewicz 1991; Edquist 2010; Freeman 1987, 1995; Lundvall 2007; Lundvall 2009; Nelson 1993). The National Innovation Systems (NIS) is generally defined as “the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies” (Freeman 1995, p. 5). Although NIS theorists have developed theories of systems of innovation at regional, international, or sectoral levels, there is a lasting emphasis on the national-level analysis as the critical institutions, laws and culture governing behaviors of actors in the innovation systems tend to be shaped at national level (see Lundvall 2007).

The central premise of the NIS theories is that innovation capabilities are created through relationships with external organizations in a broad national system of technology creation and diffusion. The performance of the innovation system depends on links between firms and a network of institutions and organizations, including suppliers, customer demand in the local market, government actors, universities and research institutes, labor markets and financial markets. Since how individual actors operate and connect to each other is important for the broad system, NIS scholars look at the roles of policies, norms, routines, and culture in shaping the incentives and behaviors of innovation actors.

Within the national innovation system, NIS theorists see the government playing a critical role in coordinating various actors and improving innovation capabilities of firms. Because of market failures in funding R&D, the government has a unique role in providing publicly funded research and disseminating the results to the business sector. The decisions to fund what types of research by the state form the basis for firms to establish innovation capabilities. The government further coordinates relationships between actors in the innovation system through which it can determine what types of knowledge can be accessed and who can have the access. In short, through providing resources for innovation and coordinating relationship to industry, the state can influence what types of innovation capabilities can be established by firms and what types of industrial activities and business models can be viable and profitable.

NIS scholars have extensively investigated the features of national innovation systems in various developed and developing economies. In the study of Japan's post-WWII economic success, Freeman conceived the idea that there is a national system for technological learning and diffusion in Japan comprising firms in the supply chains and public organizations (Freeman 1987). Lundvall concluded in early 1980s that the success of Danish agricultural equipment

industry was because of the interactions between the suppliers and the sophisticated domestic users (Lundvall 1985, 1988). In the continental US, economic historians Rosenberg and Mowery provided rich evidences on the organization and financing of R&D in the US context, covering a range of topics such as how federal investment in R&D accelerated the rate of technological discovery, the importance of military spending and government procurements on the creation of commercial technology, and how changes in the patenting and licensing rules of federally funded research give rise of the high-tech startup firms (Mowery 1992; Mowery 1998; Mowery et al. 2001; Mowery et al. 2004; Mowery and Rosenberg 1999). NIS scholars have also applied the framework to the study of developing economies by positing that the innovation systems can be vehicles for technological learning and diffusions. Research on the developing economies emphasizes the roles of the state in strengthening the capacity of domestic firms to absorb and improve upon imported technologies through articulating specific features of the innovation systems, such as public investment in scientific and technical training, creation of public research institutes for technology diffusion, and the facilitation of links between firms, suppliers, and customers (Fagerberg and Srholec 2008; Kim 1993; Liu and White 2001; Mowery and Oxley 1995).

### *2.2.3 Learning Models*

A third strand of theoretical tradition considered in this study is the view of economic and technological changes as the learning process. This view is most established in the evolutionary economics tradition (Nelson and Winter 1982, Nelson 1995, Dosi 1997, Metcalfe 1998). Evolutionary economic theorists see the learning of new capabilities by firms is of central



importance in the economic development process. Because economic development entails a break from old ways and picking up new ways of doing things, the development process involves innovation in the sense that economic agents need to take considerable risks and involve learning through lots of trials and errors. At the system level of a nation, economy or society, learning and the development of capabilities occur through the evolutionary processes of “variety creation (in technologies, products, firms and organizations), replication including imitation (that engenders both continuity and a collective element to the process of economic development), and selection (that reduce variety in the economic system and discourages the inefficient or ineffective utilization of resources)” (Malerba & Nelson 2012, p.5).

Among the Learning Models, a stream of literature worth additional attention is the late development literature rooted in the experience of successful industrialization of East Asia nations. This stream of literature argues that not only late development, as countries industrializing while advanced economies and companies are already dominating the world market, is possible; but also latecomer firms could eventually move up the technological ladder to become market and innovation leaders in their industries (Johnson 1982; Amsden, 1992, 2001; Enos, Lall and Yun, 1997; Hikino and Amsden, 1994; Kim, 1995, 1997; Hobday, 1995; Lall, 2000; Mathews and Cho, 2000). In answering the central question of how such late development occurs, the literature reveals two critical elements of industrial change: the agent of change and the process of change.

One central element of the late development literature is the emphasis on the role of agency in leading the change of country in position in economic development and international division of labor. Observing the strong states in East Asian countries in general, theorists in this tradition argue that the most relevant agent in late development is the state. Because firms in developing economies generally lack capabilities, the state with its administrative capacity must take the

charge in development. This view can trace back to historian Alexander Gerschenkron in his account of the rise of Germany and Austria, two “late industrializing” countries in Europe in the 19th century (Gerschenkron 1962). Chalmers Johnson’s work on Japanese development, which inspired the modern interest to East Asia, attribute the so-called “Japanese Miracle” of rapid economic growth is the economic bureaucracy, the “administrative guidance” from the powerful Ministry of International Trade and Industry (Johnson 1982). Alice Amsden uses the term “developmental state” to characterize the role of Korean government in industrialization (Amsden 1992). The developmental states in East Asia take up a wide range of measures to promote growth, including working closely with business in directing firms to enter high-growth industries and sectors, mobilizing capital to support large-scale investment, providing education to train a skilled labor force, helping firms to acquire foreign technology, and suppressing wages, manipulating prices and currencies to promote exports.

But even in the East Asia economies with strong state, the firms are the foundation of industrial policy and the eventual agents of industrial expansion. The East Asian firms were modernizing and even innovating in new institutional arrangements at the same time of rapid growth. It has been argued that the foundation of the Japanese industrial policy is the Keiretsu, big business groups in which industrial companies, banks, and trading companies are linked through cross-shareholdings and exclusive relationships (Smith 1998). Empowered by the financial strength from the main banks, the Keiretsu can make long-term investment, particularly in human capital through lifetime employment. But fierce competition among Keiretsu at the same time force them move quickly in introducing production techniques, improving efficiency, and introducing new products (Lazonick 2005). In Amsden’s account of Korean industrialization, she stressed that large Korean conglomerate firms are the agents of industrial expansion, and the

organizational foundation of such firms is the structure of the modern industrial enterprise. By modern industrial enterprise, Amsden refers to the type of 20th century American large companies characterized by business historian Alfred D. Chandler as large scale, multidivisional corporations administrated by salaried managers in a hierarchical administrative structure (Chandler 1977). Amsden argues that the Korea business groups (*Chaebol*), particularly large in scale and scope and with subsidies and protections from the state on the condition of meeting performance standards, provide the possibilities to break the entry barriers in markets dominated by incumbents from developed economies (Amsden 1992).

The second contribution of the late development literature is on the process of moving up an emerging firm's position in the division of labor (i.e. from simple to sophisticated activities and products), or so called "catch up". The phase "catch up" reveals that scholars in this tradition generally believed that the success of emerging firms means the close resembling of leading firms from advanced economies. For historical reasons, a well examined case in the literature is the Korean companies. Amsden argues that, the success of Korean industrial companies is attributed to learning. In late industrialization, learning is the primary sources of growth, instead of invention and innovation-based growth in earlier industrialized economies. For the Korean industrial companies, the most critical part of learning is learning on the shop floor, carried by well-educated salary engineers, who assimilated and optimized the technologies acquired through various channels and transform the technology into better manufacturing (Amsden 1992).

Other scholars have taken a view that the learning and catch-up process occur in sequences. Mike Hobday's study of latecomer firms from the Asian Tigers (South Korea, Taiwan, Hong Kong, and Singapore) in the electronics industry suggested a model of catch-up in the sequence of "OEM – ODM – OBM". In this model, latecomer firms use subcontracting and OEM (Original Equipment

Manufacturing) mechanisms to enter the industry as simply assembly for leading foreign firms, and then to assimilate process and product technologies through formal and informal technical assistance in the contractual relations. Through this process, the latecomer firms might need to make incremental improvement in process technology and engage in reverse engineering in developing product technology. With sufficient technology capabilities accumulated, the latecomers advance to the position of designing and making products for customers, or ODM (Original Device Manufacturing). In the final phase, selective latecomer firms could become Original Brand Manufacturing (OBM) through investing in in-house R&D. While this path from simple manufacturing to genuine innovation is clear, Hobday admits, it does not work for the majority of the firms. Among the companies in his study, few genuine innovations were generated locally, and most of the firms never grow beyond the ODM phase depending on international competitors for key components, capital goods, and distribution channels (Hobday 1995). Another notable model is Limsu Kim's "imitation to innovation" model. Kim distinguished between "duplicative imitation" of mature products through reverse engineering and "creative imitation" of existing products with differentiations in features and performances. To progress from duplicative imitation to creative imitation and then to innovation, it requires accumulation of technology capabilities. Kim shows that the rate of technological learning depends on existing knowledge base and intensity of efforts. Existing knowledge base can be improved by technology transfer, while the intensity of efforts may be managed in creative ways conforming to social norms in the firm, such as constructing crisis to expedite learning in Korean firms. Kim argues, what enabled the success of Korean firms in the transformation from imitation to innovation is a broad set of factors, including "government, *chaebols*, education, export policy, technology transfer

strategy, research, development policy, sociocultural systems, and private-sector strategy” (Kim 1997, p194).

The Late Development literature had shown clearly that a static world in Product Cycle theories can be changed, with the right agency and following a process. Yet, as globalization and modularization challenged Product Cycle theories, there are questions of whether the traditional industrial policy is viable under intensified trade liberalization and strengthened international IPR regime (Cimoli et al. 2008). Breznitz’s (2007) study of three emerging economies (Israel, Taiwan, and Ireland) from the 1990s, for example, provided an updated view of late development under globalization. Breznitz argues that, in the age of globalization and modularization, emerging economy firms are more likely to be successful in specific stages of global production based on their specialties and pursue “production stage economies of scale”, rather than trying to resemble the old integrated firms of the 20<sup>th</sup> century. There is still a role for the state, but the role is in creating capabilities for firms and lowering barriers to enter specialization, rather than trying to create all-winning national champions. In Breznitz’s view, specialization in stages of production could involve innovation adding values to new process and product creation, and it is a valid path towards building a wealthy nation. Nevertheless, this path to development in many ways do more to enhance the international division of labor rather than challenging the prevailing order as scholars of the previous generation argued.

### *Discussion*

The three prevailing views on innovation have thus focused on a set of factors to understand how innovation occurs and how innovation capabilities are created. The Product Cycle theories

established a world view that innovation can only occur in advanced economies and it is carried out by firms possessing advanced skills and supported by developed markets, while developing economies receive industries only when the technology has been standardized and commodified. The Learning Models bring motion into the static world of the Product Cycle, and introduce the role of agency, in which the state can assist learning firms to acquire capabilities through appropriate policies. The system models point out that, not only the state, but also a broad set of actors and organizations embedded in the national institutions external to the innovating firm can jointly shape firm-level innovative capabilities and outcomes.

Although the three streams of literature have different approaches and focuses, there are three recurring themes spanning their views on innovation. First, scholars in three traditions agree that, innovation requires the integration of a broad set of capabilities, ranging from product design, engineering, manufacturing, to marketing, distribution, and coordination capabilities. The Product Cycle theory is explicit that only firms in the advanced economies can master this wide range of capabilities to engage in innovation, while the Learning Models see development and catch-up as the process of widening existing sets of capabilities. The system models position that different types of relationships with external organizations lead to the development of different types of capabilities.

Second, the development of innovation capabilities is an accumulative process. The Product Cycle theory perceives that there is a hierarchical order in skill requirements for various types of business activities and capabilities required to engage in innovation, with manufacturing and assembly requiring the lowest and design, marketing and R&D requiring the highest skills. The Learning Models, especially the Late Development literature, accept this view by arguing that the latecomer firms must learn through a sequence of reverse Product Cycle, in which the firms

progress from low-skill requirement activities in manufacturing and assembly to advanced capabilities in R&D and marketing. Even literature on the system models have described innovation systems in developing economies as systems of learning and absorbing imported technologies.

Third, innovation occurs within the boundary of business firms, and the firm is the primary vehicle for accumulating innovation capabilities. The Learning Models mostly clearly articulate this view that in late development, business firms, under the guidance of the state, carry out the process of learning and technological accumulation. While the system models emphasize that the firms have to draw resources from the broad national economy to develop different types of innovation capabilities, the models have conceded that it is within the firms the resources and opportunities are combined and transformed into capabilities for innovation.

On the other hand, there are significant disagreements within the literature, especially on the issue of how innovation pathways occur. Product Cycle and other stage models explain firm behaviors through their positioning in the innovation process and stages, but the models see changes to firm's positions are exogenous thus are not explained within the model. The System Models tend to be static as well, but policy interventions are recognized to have a role in changing system states, even though institutional changes are notoriously difficult. The Learning Models are most dynamic among the three. In their conceptualization, innovation pathways can evolve over time, as expertise and knowledge is gained. But the changes are also path dependent, as previous experience could favor certain pathways while blocking others.

### **2.3 Theories of Innovation in China: Current Debates**

Although China's unprecedented growth since the 1980s has stimulated much research on its economy, the debates over innovation in China is recent. The early debates in the 2000s were centered around whether there are novel innovations in China, in the sense of searching for discoveries at technological frontiers and the creations of new-to-the-world products and services. On one hand, in the midst of an economic boom after China's accession into WTO, scholars and policy makers observed that the majority of local firms were trapped in low value-added manufacturing activities, depended on imported high-value components to assemble and process, and had no signs of engaging in novel-product development (Cao 2004; Steinfeld 2004; OECD 2006). The pessimistic view was closely linked to the Chinese government's adoption of "indigenous innovation" (自主创新) policy in 2006, which seeks to reduce dependence on foreign technologies and promote local technological development. On the other hand, others have claimed that China is already an innovative economy by looking at the number of academic publications and patents in selected scientific and technological domains (e.g. Nanotechnologies) (Porter et al 2009).

By the end of the 2000s, it has become increasingly clear that there are some forms of innovation in China, although those innovations could take forms distinctive from the perceived ways of innovation in the West, such as that in the Silicon Valley or the Route 128. Nowadays the debate has moved to the questions of specific models, rates, directions and impacts of innovations in China. Several theories have been put forward to characterize Chinese innovations and link them to various socioeconomic factors, including relations to the state, Chinese S&T system, structure of the Chinese market, and relationships with the global production system and



multinational companies. In this section, I will briefly review the representative works in this debate, link them to the theoretical thoughts in innovation theories, and discuss their limitations.

A pioneering work recognizing innovation in China is Lu's study of the computer electronics industry (Lu 2000). Lu documents the emergence of four large-scale Chinese computer enterprises – the Stone Group, the Legend Computer Group (Lenovo), the Founder Group, and the China Great Wall Computer Group – which built their business by introducing technologies and products ahead of MNCs in niche Chinese markets, including Chinese language processing cards for early PCs and Chinese language electronic printing systems. Lu calls those Chinese inventions in electronics “indigenous innovation” in the sense that these technologies were based on research and development in the legacy Chinese S&T system from the planned economy era, but it was the emerging *minying* (non-state) firms which transformed the inventions into commercial success. The *minying* firms were new forms of organization created in the reform, which often had mixed ownership structure and maintain the autonomy from the state in investment, organizational, and technological decisions. The new gained autonomy, Lu argues, allowed *minying* firms to properly incentivize employees and maintain investment in technology development and capability building (Lu and Lazonick 2001; Lazonick 2004). The idea of “indigenous innovation” has been pushed further recently by Lazonick and Li, who argue that there is a general process in China that the state invests in physical and human infrastructure, transfer technology from abroad and improve upon it, and based on which indigenous innovation by business enterprises occurs (Lazonick and Li 2013).

In a similar line, Shen (1999) had documented the R&D of an ingenious digital telephone switch prototype and its diffusion in the domestic industry that gave rise to competitive Chinese telecommunication equipment companies. While Lu and Shen's work was unique, they

contributed to the understanding the rise of the Chinese computer electronics and telecommunication equipment, two industries showed international competitiveness and innovation potential early on.

Yet, for most scholars, the uniqueness of the Chinese market in its size and complexity and the opportunities for innovation it might offer catch the imagination. A large stream of literature on Chinese innovation has intended to address the role of the Chinese market as a key driver for industrial innovation (Mu & Lee 2005; Brandt & Thun 2010, 2016; Gadiesh, Leung, & Vestring 2007; Zeschky et al 2011; Zeng and Williams 2009). Within this literature, there are two approaches. In the first approach, the industrial economists argue that the Chinese markets provide opportunities, but it is ultimately a stepping stone for local firms to accumulate capabilities to eventually compete in the world market. Those scholars find that the Chinese internal market, especially parts of the domestic market that are segmented from the world market for reasons such as cost structure and consumer preferences, provides unique entry opportunities for Chinese companies in a range of mid- to high-tech industries (Mu & Lee 2005; Brandt & Thun 2010, 2016). Those segmented markets filled with demands for lower price and lower quality products provide natural protections for local companies, who can compete on a cost structure that is prohibitive for multinational firms. To participate in this market, multinational companies must localize to lower costs, and the localization in turn creates spillovers in the supply chain and further benefit local companies. Economists Brant and Thun argued such feedback effects and fierce competition in the low- to mid-end markets create self-reinforcing dynamics for industrial upgrading that gradually improve the quality of local products and technologies (Brandt & Thun 2010, 2016).

In a second approach, the business scholars claim that innovations spring out of unique conditions of China and other emerging markets are a class of innovations with their own rights.

Those innovations are often called “frugal innovation”, because the manufacturers innovate by cutting back premium features designed for high-income economies to save costs and introducing twists to the products to meet local demands. Examples of “frugal innovation” include white goods with reduced size or customized to fit the small and congested kitchens in Asian countries. Since those markets demanding for frugal innovations tend to be more sensitive to prices rather than quality, which again create entry barriers for multinational companies, they are often called “good enough markets”. Scholars in this approach argue those low-cost innovations are not necessarily entry points for higher technologies, but because good enough markets widely exist in the developing world, companies succeeding in these markets are occupying a unique niche in the global marketplace (Gadiesh, Leung, & Vestring 2007; Zeschky et al 2011; Zeng and Williams 2009).

In early 2010s, Breznitz and Murphree (2011) synthesized streams of research and advanced a model of Chinese innovation. They call this Chinese model “Run of the Red Queen”, a special case of fast follower model in which Chinese companies follow closely to the technological frontier to reap gains from innovations developed somewhere else with established markets (Breznitz & Murphree 2011). The “Red Queen” model is shaped by both Chinese internal political institutions and the global production system. On one hand, building on the Chinese regionalism literature, Breznitz and Murphree argue the internal politics in China created a status of “structured uncertainty” since the reform, in which the political center allows competing regions to experiment economic policies without ex-ante commitment to specific policies or models. On the other hand, globalization has led to “industrial fragmentation” along the supply chain, breaking down stages of production to be conducted by separate firms across national borders and lowering entry barriers for firms pursuing vertically specialization. The combined effect of “structured

uncertainty” and “industrial fragmentation” is an industrial innovation system that encourages firms to adapt innovations quickly and innovate incrementally but shy away from long-term and risky investment in radical innovations. Breznitz and Murphree compared IT industries in three Chinese regions, Beijing, Shanghai, and Shenzhen, and argue that even though the three regions had rather distinctive historical trajectories, their innovation models are all excelling in rapid, second-generation innovation and process innovation, thus converging on the “Run of the Red Queen” model.

More recently, Nahm and Steinfeld (2014) claim that Chinese companies have evolved beyond the stage of squeezing value out of existing products and designs, but instead, these companies operate at the technology frontier through specializing in “innovative manufacturing” (Nahm & Steinfeld 2014). By “innovative manufacturing”, they mean manufacturing activities to materialize new-to-the-world design, involving learning, experimenting, and innovating at technological frontier. By investigating the solar and wind power industries, Nahm and Steinfeld find that the specialty of Chinese innovation is its unique capabilities surrounding manufacturing scaling-up, technology commercialization, and manufacturing-related innovations. They attribute such innovation models to the engineering capabilities accumulated in Chinese firms and the cross-border collaboration among firms specializing in different stages of the value chain.

**Table 1 Theories of Chinese Innovations**

<b>Theory - Scholar</b>	<b>Innovation Model</b>	<b>Explanatory Variables</b>	<b>Path to technological frontier</b>	<b>Theoretical tradition</b>	<b>Industry</b>
Indigenous Innovation (Lu 2000; Lazonick 2004; Shen 1999)	Novel technologies in niche (Chinese) markets	Knowledge base from the legacy S&T infrastructure; Growth of non-state firms	Leapfrogging – From invention to simultaneous development of innovation and manufacturing capabilities	Learning models; System models	Computer electronics
“Good-enough” /Frugal Innovation (Gadiesh, Leung & Vestring 2007)	Redesign of existing products to reduce premium features and costs and adapt to local markets	Demands form cost-conscious new middle class in emerging economies	Ladder climbing - From manufacturing to innovation as capabilities accumulate	System models	Consumer durables
Middle market innovations (Brandt & Thun 2010; 2016)	Reengineering of existing products to fit for middle market and upgrade along a quality ladder	Natural protection of local firms from low end market; spillovers from localization of MNCs; competition on the middle market	Ladder climbing - From manufacturing to innovation	System models	Automobile, Construction equipment, Motorcycle
“Run of the Red Queen” (Breznitz & Murphree 2011)	Fast follower strategy & incremental improvement to reap economic gains from innovations	“Structured uncertainty” in Chinese political institution; production fragmentation in global production network	Stage specialization (in manufacturing)	Stage models	ICT industries in general
Innovative manufacturing (Nahm & Steinfeld 2014)	Manufacturing-related innovation in scaling-up, architecture design, and technology commercialization	Engineering capabilities in Chinese companies; (cross-border) collaboration of firms specializing in different stages of production	Stage specialization (in manufacturing)	Stage models	Solar power & Wind turbine

Table 1 summarizes the five prevailing views in recent debates on characteristics of innovation in China. These views, while deeply embedded in the Chinese context, can be linked to established theories of innovation. The “Run of the Red Queen” model and the “Innovative Manufacturing” argument share a view of the Product Cycle theorists that China as an emerging economy specializes in low- and middle-skill activities, but they also advanced the classic stage model by arguing that such specialization creates unique innovation capabilities. The “Run of the Red Queen” model claims such unique capabilities are process innovation and second-generation innovation at rapid speed, and under modularized production, such capabilities allow Chinese companies to reap gains in the forms of employment and growth from innovation developed elsewhere. Comparing to the classic Product Cycle theory, low- and middle-skill specialization under the “Run of the Red Queen” model is more economically viable in generating economic profits for China. The “Innovation Manufacturing” argument claims that specialization in manufacturing might in fact be unique capabilities for scale-up and commercialization, as the collaboration between design and manufacturing firms in the supply chain can replace the in-house coordination in traditional innovating firms between R&D and manufacturing for product development. While both the “Run of the Red Queen” model and Innovation Manufacturing describe well the strength and weakness of current innovation models in China, they are quite limited in predicting changes. In fact, both models incorporate a path dependence view that China’s current specialization is a resulted from past institutional configuration and accumulation of manufacturing experiences. Yet, from both models, it cannot tell whether Chinese firms can broaden their capability sets to engage in frontier innovations in the future, or whether their advantages in manufacturing and second-generation innovations would be eroded by factors such as raising wages.

The “Good Enough” innovation and Middle Market innovation models are essentially system models emphasizing specific elements in the innovation system. In the Good Enough innovation model, the innovation capability of firms is shaped by the characteristics of local market, which is an emphasis on price and local tastes. The Middle Market innovation model focuses on both the characteristics of local market and relationship with suppliers, and the model adds a dynamic dimension in the interaction of the two elements: the competition for the low-cost, decent-quality middle market drives for the localization of MNC’s supply chains and the upgrading of local suppliers, which in turn accelerates the upgrading of local firms through supplier relationship. Like system models in general, both models are static in the sense that the characteristics of innovation behaviors are determined by features in the systems. By excluding the roles of agents, such as the government or entrepreneurial firms, there is no clear pathway for changes in the system, i.e. how the Chinese firms move beyond the good enough or middle markets.

Finally, the indigenous innovation argument blends the system models with learning models. The emergence of indigenous innovators draws on resources from national R&D infrastructure, but how they transform the resource into capabilities and gradually broaden capabilities is a process of learning. Institutional arrangements including public funded research and government-business relationship are instrumental in the learning process. Unfortunately, much of research in this stream, especially firm-level empirical analysis, are done in the late 1990s. Thus, they need to be updated, as there are rapid changes in the Chinese economy.

It should be noted that there is an alternative view of perceiving China’s progress in advanced technology industries as the results of state mercantilism, especially in the US policy community. In a series of reports from the Information Technology and Innovation Foundation, an influential US-based think tank, Atkinson and colleagues have called out China’s innovation

policies and practice as “Innovation Mercantilism”, which is a broad set of policies and practices to provide unfair advantages to Chinese firms at the expense of foreign competitors (Atkinson 2012; Atkinson & Ezell 2015; Cory 2016; Nager 2016). They argue that the overarching goal of Chinese innovation mercantilist policies is to acquire foreign technology and know-how, and technology transfer and local production requirements as a condition of market access in China remains a key policy (also, see Hout and Ghemawat 2010). While such conditions might contravene China’s WTO commitments, Atkinson claims that Chinese officials resort to informal channels to pressure foreign firms<sup>2</sup> (Atkinson 2017).

In addition, Atkinson finds that Chinese mercantilist policies include: using anti-monopoly law to force foreign companies to license technology to Chinese firms at favorable rates; theft of foreign intellectual property (IP); barriers or even denial of access to Chinese markets in certain sectors on the ground of security; government-subsidized acquisition of foreign technology firms; domestic content requirements; homegrown technology standards; limiting exports of rare earth elements. These policies are widely practiced in almost every advanced technology industry from ICT and renewable energy to aerospace and biotechnology (Atkinson 2017).

In a similar vein, Haley and Haley (2013) argued that government subsidy plays a major role in China’s transition from labor-intensive industries to the world’s largest manufacturer and exporter of capital-intensive, high-technology goods. They estimated that industrial subsidies in five key industries they studied, including steel, glass, paper, and auto parts, might exceed more

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<sup>2</sup> Contemporary Chinese mainstream policymakers, however, have considered the idea of “Trade Market for Technology” to be out-of-fashioned. See, for example, a 2017 article on *People’s Daily*, the CCP’s flagship newspaper, criticizing this idea (in Chinese) < [http://paper.people.com.cn/rmrb/html/2017-06/20/nw.D110000renmrb\\_20170620\\_2-05.htm](http://paper.people.com.cn/rmrb/html/2017-06/20/nw.D110000renmrb_20170620_2-05.htm) >



than thirty percent of production costs. In another word, they argue the Chinese advanced technology industry would not exist without government subsidies.

The problem of the “Innovation Mercantilism” argument is that it is not grounded in innovation theories. Policy analysts in this camp see advanced technologies as blueprints or bits of information that can be bought, stolen, and easily implemented in a new environment. Yet, there is a general agreement in innovation theories that technology transfer is difficult. Even absorbing advanced technologies requires accumulations in skill sets, the necessary R&D, and industrial supporting infrastructure, and it involves painstaking learning processes. Not to mention improving upon absorbed technology to create advantages over the original innovators. It is true that the Chinese state might have indeed coerced foreign firms for technological transfer or intends to acquire foreign technologies for the domestic industry to create innovation capabilities. Such strategy did not work in the past (Zhou, Lazonick and Sun 2016; Li 2016), and if it is working now, it implies that China must have already developed an impressive array of capabilities to absorb the advanced technologies. But how China developed such capabilities would not be explained by the “Innovation Mercantilism” argument.

The discussions so far have shown that there is a heated debate on Chinese innovation in both the academia and policy communities. Yet the current debate is limited in understanding the emergence of innovation capabilities, especially at technological frontiers, in China. Theories of innovation have long pointed out, to engage in novel innovations, it requires the integration of a broad set of skills and capabilities, and the accumulation of such capabilities takes time. So far, the theories of Chinese innovation only focus on a narrow set of capabilities such as process innovation and manufacturing (e.g. “Run of the Red Queen” model, Innovation Manufacturing argument) or specific stages of capability accumulation (e.g. Middle Market model). To

understand China's emerging innovation capabilities, we need a comprehensive understanding of the process of accumulating different types of capabilities in China. Thus, we need a new framework for such a task.

## **2.4 Research Framework**

This study examines how innovation capabilities are developed and accumulated in the world's largest emerging economy, China. The process of accumulating capabilities to the point that it allows firms to engage in frontier innovation is what I call innovation pathways. What factors shape the innovation pathways in China? To answer the question, the framework offered here builds on insights from established innovation theories, but considers the unique contexts of Chinese development, especially the features of a large and open economy, deep embeddedness in globalized production, and a strong role of the state.

The framework builds on the premise that, innovation at technological frontiers relies on a broad range of capabilities, not only in invention through research and development, but also in manufacturing through scale-up in mass production as well as commercialization through establishing sales and distribution channels. As innovation theorists have long pointed out, the development of novel technologies and products often involves integrations of an array of capabilities in the form of coordination between different types of industrial activities, such as establishing links between marketing and R&D to understand market demand and customer needs, joint problem solving between R&D and manufacturing in scale-up and mass production, and so on. In a capitalist economy, firms are the primary social organization for such integration of capabilities to occur, as the firms carry out the tasks of transforming technologies into products

and services saleable in the marketplace; and since the development and integration of capabilities do not happen overnight, the firm is also the vehicle for the accumulation of innovation capabilities (Lazonick 2007).

Firms rely on the national R&D infrastructure and institutional arrangements to assemble and combine resources, capabilities, and market opportunities distributed broadly in the economy to begin the process of capability building and accumulation. Scholars of National Innovation Systems posit that firms establish innovation capabilities through linkages with external organizations. There are essentially two types of linkages at work in a firm's innovation process: the forward linkages to market, which determine the opportunities to profit from innovations; and the backward linkages to suppliers, universities, public research institutes, and government actors that provide inputs, resources, and capabilities to feed into the innovation process. Accordingly, the state has a major role in shaping innovation capabilities of firms in the national innovation system through: providing public funded research; coordinating relationships between firms and other actors; and regulating markets to influence profitability of different types of industrial and innovation activities (Freeman 1987; Lundvall 2007, 2009; Nelson 1993).

Firms might also acquire necessary capabilities and market access through participating in globalized production. The global production system can potentially substitute or enhance elements of the national innovation system in two ways. One way is through recruiting local firms to produce for MNCs as subcontractors, the global production system provides as an alternative to the domestic market – exporting to the world market that is potentially larger and more sophisticated. The other way is through membership to networks of suppliers and subcontractors, local firms gain accesses to critical resources and complementary capabilities necessary for innovation processes. In both ways, participating in global production could potentially reduce

linkages to the domestic market and national R&D infrastructure (Baldwin and Clark 2000; Berger 2005; Camuffo 2004; Ge and Fujimoto 2004; Gereffi et al. 2005; Langlois 2002; Steinfeld 2004; Sturgeon 2002; Hobday 1995; Kim 1997).

The process of developing, accumulating, and combining capabilities by firms in a national economy until the point that the firms can engage in novel innovations at technological frontiers is what I call an innovation pathway. An innovation pathway is a shared pattern of capability development among firms in one or more industries in the same economy at a given stage of economic development. While an individual firm may develop its own idiosyncratic set of capabilities through a company-specific history, the shared pattern of development for firms in a national economy might emerge, exactly because of the shared institutional contexts in terms of laws, regulations, customs, and routines, providing the same advantages and limitations in the development process (Lundvall 2007; Malerba and Nelson 2003). Additionally, sharing markets might also cause firms to converge, as competitive pressures tend to force weaker firms to imitate the leader (DiMaggio and Powell 1983). Nevertheless, there may be more than one innovation pathway in a national economy. Sectoral differences can lead to vastly different innovation patterns (Pavitt 1984), and differences in regulations towards different types of firms (e.g. state-owned vs. private firms) might also lead to differences in resource constraints, especially in the case of China (Huang 2003).

Considering the context of Chinese development, I propose that innovation pathways are shaped by three sets of factors relating to the state, market, and globalization. The three sets of factors broadly determine the opportunity structure and resource provision that Chinese firms can access to in the accumulation of innovation capabilities.

The first and foremost important set of factors relate to the roles of the state. In the Chinese context, I consider three types of state intervention in the economy. First, the state influences the operation of industrial firms by determining the governance structure for business. In the Chinese context of economic transition from planned to market economy, it is up to the state to allow or discourage firms with certain types of governance institution (i.e. private or mixed ownership). Depending on policy goals, the state might also decide the levels of strategic autonomy a firm can achieve in deciding its investment strategy and organizational structure. By setting these institutional parameters, the state can influence what types of firms can grow and what innovation strategies might emerge. Second, the state invests in science & technology infrastructure and human resource, which provides the foundation for business firms to form innovative capabilities. By determining what types of R&D and education projects to be invested, who can access and benefit from these projects, and how the business firms are involved, the state can influence what types of innovation capabilities can be established by firms internally. Third, industrialization and innovation projects require mobilizing large sums of capital, and the organization of finance is controlled by the state. The state can influence the provision of industrial financing, by deciding which parts of the government undertake the development projects, and what types of instruments are used. Through influencing firm-level investment decisions, the state would ultimately influence the process of accumulating innovation capabilities. In short, the state influences the innovation pathways by providing institutional foundations and various types of resources to business enterprises for innovation, and regulating how these resources are accessed.

The second set of factors is the characteristics of the domestic market that shape the opportunities to profit from innovations. While the government can influence the working of markets through regulations, characteristics of markets that matter for innovation such as income

levels and customer tastes are largely forces of their own (Porter 1990). In the case of China, I consider four characteristics of domestic markets that influence innovation pathways: the size, depth, segregation, and competition level of the market. The size of the market determines the scale and scope individual firms can operate. The level of segregation of local markets from the world market, which is often results from differences in culture, user preference, and income levels, can influence the level of natural protections that can provided to local industries. The depth of the market, or measured as the income level and sophistication of users, influences the opportunities provided for learning from users and generating new ideas. Finally, the level of competition in the market influences whether the business firms have sufficient incentives to upgrade or engage in risky innovation activities.

Globalization influences the innovation pathways by providing the third and final set of factors that can potentially substitute or enhance elements in the national system of innovation. Participation of the global industry changes the relationship of local firms with domestic market and national industrial base. Producing for the world market provides an alternative to the domestic market, and the world market is potentially larger in size and more demanding in quality. On one hand, the exporting market might allow firms to achieve economies of scales and/or produce high-quality goods otherwise impossible. On the other hand, dependence on exporting, which usually is mediated by MNCs, limits the chances for the local firms to develop capabilities for marketing, distribution, and understanding markets. Participation in global production also influence backward linkages to local suppliers and R&D infrastructure in a similar way. Subcontracting for the multinational corporations provides learning opportunities, especially under the guidance and supervision of leading firms such learning can be efficient. The global production systems provide shared infrastructure and networks of suppliers, allowing local firms to tap into resources and

capabilities that they would not be able to develop by their own. At the same time, embedding in global production system could also isolate the firms from participating broadly in the local R&D infrastructure.

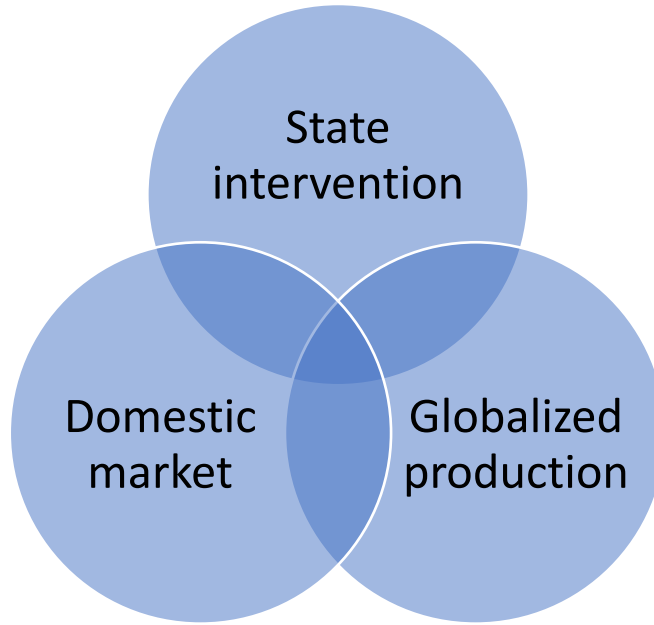
The three sets of factors related to the state, domestic market, and global production rarely influence the accumulation of innovation capabilities independently. It is the interactions of two or more sets of factors that create favorable conditions for innovation pathways to occur (Figure 2). The interactions of the state, market, and globalization factors can be used to explain historical and contemporary innovation pathways in industrialized and emerging economies. The earlier industrializations in the 19<sup>th</sup> century and early 20<sup>th</sup> century, such as those in the United States and Japan, might be considered as innovation pathways at the intersection of active government policies and supporting domestic market conditions. These nations jumpstarted industrialization through high tariff, subsidies, and other protectionist policies. In the US, a large domestic market allows business to achieve economies of scale and scope, while in Japan, government worked closely with selected large business group and channeled resource to foster their growth. In both cases, intensive domestic competition, rising income levels, and government investment in education allow the emergence of innovative enterprises before these firms enter international competition (Chang 2002, Gordon 2004).

The experience of the East Asia NIEs is a case of combining active roles of the state and globalized production. The export-driven growth is a result of both export promotion government policies and offshoring strategies of multinational corporations. Learning occurs through knowledge flows in the subcontracting relations, allowing local firms to climb technological ladders through mastering manufacturing first and developing marketing, design and R&D capabilities later. Active government interventions complement the learning process in developing

leading industries. In South Korea, the government supported selected large enterprises to diversify into high-barrier industries, such as automobile, petrochemical and semiconductor (Amsden 1992; Hobday 1995; Kim 1997). In Taiwan, the government developed public agencies to acquire, assimilate and diffuse critical semiconductor technologies that private sector is unable to develop, and spin out world leading semiconductor foundry firms of TSMC and UMC (Fuller 2004; Breznitz 2007).

The emergence of many successful non-state firms in China occurs at the intersection of favorable domestic market conditions and intensive globalization of production, while the role of the state is absent. A large and expanding local market with differentiated tastes provide opportunities for the non-state firms to survive and develop unique capabilities in marketing, sales and distribution to control local markets. These capabilities are complemented by accessing to productive capabilities in shared supply chains with the multinational corporation, which developed the open technology platforms and supplier networks for cost saving. Fierce competition and rising incomes in the domestic market incentivize the Chinese OEMs and suppliers to upgrade constantly to keep pace with market changes and wage growth (Zhou 2008; Brant and Thun 2010; 2016).





**Figure 2 Research Framework**

In this study, I further contend that the development and accumulation of capabilities for engaging in frontier innovations, or what I call the emergence of innovation pathways, is most likely to succeed when the government policy synchronizes with the development of domestic market and the evolution of global industry. By synchronization, I mean that the resource, capabilities, and institutional framework provided by the government enable firms to combine and integrate market opportunities and complementary capabilities provided by domestic market and global industry. In the context of China, a large and multi-layered domestic market with rising incomes and increasingly sophistication provides the opportunities for local firms to generate revenue, learn about customers, and develop sales and distribution capabilities, while the presence of global production networks laid down by multinational corporations provides a broad array of capabilities and infrastructure, from advanced components to high-quality contract manufacturing, that can be tapped into. To enable Chinese companies to combine such opportunities and resources

for innovation success, the state can synchronize by investing in advanced S&T knowledge and human training, financing long-term and risky R&D projects, and providing institutional supports for firms engaging in the combination and accumulation process.

As world-class innovations are still rare in China, the government policy is often asynchronous with market and globalization developments. The most important type of unsynchronized development is the absence of the state in providing key resources and capabilities for innovation. By far, Chinese companies, especially non-state high-tech companies, achieved most successes by leveraging domestic markets and access to globalized supply chains, and the absence of the state initially promotes competition and autonomy in these industries. However, such model has limits. Relying on the capabilities in the supply chains to serve Chinese market often result in a fast-follower status that is those Chinese firms are only good at second-generation innovations and the type of design and marketing capabilities specifically targeting Chinese consumer preference (cf. Breznitz and Murphree 2011).

There are other types of unsynchronized development. The Chinese government had leveraged domestic markets to build state industries, but implemented a strategy of building a domestic industry isolated from the global industry, these state projects risk losing dynamism and becoming outdated quickly. There are Chinese industries that have developed exclusively through exporting, often assisted by local governments. Most of such industries are struggling to elevate their status in the global value chains, and often they need to target back to the local markets to build marketing and distribution capabilities. The case of the solar photovoltaic industry is a peculiar case in which Chinese companies, nurtured by local governments, achieved a fair high level of success through exclusively exporting. However, the industry had faced great difficulties in the late 2000s because of the slow development of domestic markets (Hopkins and Li 2016).

While synchronization can accelerate the process of capability accumulation, there is no guaranteed that firms would succeed in moving to the frontiers of innovation under synchronization. The accumulation of innovation capabilities is a long-term, risky, and collective process that requires firms to make deliberate strategies for investing in innovation, mobilize and integrate skills to engage in learning, and sustain the learning process through committed funding (Lazonick 2007). In other words, innovation pathways are intrinsically difficult and risky.

Innovative firms can also achieve innovation success under unsynchronized policies. Firms can still develop capabilities to exploit market, tap into complementary resources offered by the global industry, and insert itself in a stronger position in the production networks through investing internally in core R&D, marketing, and manufacturing capabilities without state assistances. However, such process would be more challenging and chances for success would be even lower.

## **2.5 Methods**

### *2.5.1 Research Method*

In this study, I explore the phenomenon of emerging innovation pathways in China. Beyond presenting a description of this phenomenon, my aim is to develop new theories to explain such phenomenon. To achieve these objectives, I carry out the empirical study at two levels of analysis: a macro-level analysis of national economic and institutional conditions and a micro-level analysis of industry and firm dynamics.

The macro-level analysis is used to provide a contextual understanding of the three sets of factors identified in the framework, and how state, market, and globalization institutions work in

the Chinese economic development environment. I employ a variety of historical records, statistical data, and existing researches in a comparative historical analysis, in which I analyze the socioeconomic processes unfolding in China with comparison to similar processes in other time and places (ASA 2011; Lazonick and Li 2013).

To investigate micro-level dynamics, that is, how individual industrial firms develop and accumulate innovation capabilities, I make use a case study approach. The case study method is defined as “an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context” (Yin 2009, p. 18), which is particularly relevant to the type of explorative and contextual characteristics of this study. The case study approach provides two main advantages. First, detailed case data provide rich information from various sources and different perspectives, allowing the development of deep understanding of the phenomenon and underlying mechanism (Eisenhardt & Graebner 2007). Second, case study is suitable when investigating a phenomenon in its context without clearly defined boundaries between context and phenomenon. This is especially useful as the phenomenon being investigated (innovation pathways) occur in a fluid and changing institutional environment (China) where unexpected factors can intervene with the phenomenon. Case study allows not only capturing changes of a phenomenon but also provide an understanding of why changes happen and how underlying factors drive the changes (Yin 2009). I use a theory-guided case study approach throughout the study. That is, a tentative theory (“innovation pathways are mostly likely to emerge at the synchronization of state policy with market and globalization developments”) is developed from literature to define the scope and emphasis of this study, but the purpose is not to first deductively determine a theory and then test it against empirical reality. Rather, this study follows the method of iterative theory building, in which the researcher first openly examines empirical reality and then through an iterative process

going back and forth between theory and fieldwork to develop a theory (Eisenhardt 1991, Glaser and Strauss 2009, Yin 2009). Two detailed cases with sufficient within-case and cross-case variations are used to build the theory, enabling a comparative case study approach (Eisenhardt and Graebner, 2007; Siggelkow, 2007). This approach provides greater rigor and generalizability of the findings compared to a single case study (Eisenhardt, 1991).

The case study research is conducted in three phases: (1) case selection, (2) data collection, and (3) data analysis (Yin, 2009). The phases do not necessarily follow a linear sequence but may involve iterative and overlapping work. Case analysis follows the tradition of institutional-industry studies. The industry studies tradition analyzes patterns of behaviors, including interactions, competition, and cooperation among players of the industry that constrain and support the development of certain capabilities, as well as the institutions that motivate particular behaviors of economic actors (Piore and Sabel, 1984; Fligstein, 1990; Lazonick, 1990; Powell and DiMaggio, 1991; Lundvall, 1992; Nelson, 1993; Zysman, 1994; Herrigel, 1996; Kenney, 2000; Lester and Piore, 2004; Breznitz and Murphree, 2011).

### 2.5.2 *Case Selection*

This study is built on series of fieldworks in studying Chinese high-tech industries spanning from the summer of 2012 to the spring of 2017. During these trips, I interviewed people from various companies and government agencies, in China's three major industrial and innovation clusters: Beijing, Yangtze River Delta, and Pearl River Delta. Cases for this study is selected from this larger pool. The goal is to select cases in order to maximize what could be learned in relation to the research objectives (Eisenhardt, 1991). I identify two cases, the telecommunication

equipment industry and the semiconductor industry, as representative cases to illustrate the emerging Chinese innovation pathways.

The two industries share important similarities. They are both subsectors of the information and communication technology (ICT) industry, which is the driving force in China's industrialization and continues to be the strongest and most innovative industry in the country. Per data from the U.S. Census Bureau, the ICT industry accounts for a monster share of 90% in Chinese advanced technology products export to the U.S. in 2016<sup>3</sup>.

All three sets of factors in the framework have strong presence in the two industries. The Chinese government practiced industrial policies in both industries. One type of evidence is that among the 13 National S&T Mega Projects launched in 2006, there are three mega-projects, i.e. high-end chips and software, semiconductor manufacturing, and mobile broadband, are targeting the two industries. It should be noted that half of the mega-projects are investing in technologies of security implications, such as aerospace and global positioning systems, or public in nature, such as nuclear power or water treatment. But these three mega-projects for the two industries are explicitly targeting commercial technologies, reflecting the government ambition for innovation and technology advantage. In both telecommunication equipment and semiconductors, China is largest single market in the world. Both industries are highly globalized, with fragmented supply chains dispersed across North America, Europe and Asia.

There are important differences between the two industries, however. The most important difference is the level of innovation success. In the telecommunication equipment industry, the Chinese company Huawei Technologies has already become an international innovation leader.

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<sup>3</sup> US Census Bureau data on the imports and exports of Advanced Technology Product group by country is retrieved from <<https://www.census.gov/foreign-trade/statistics/product/atp/select-atpctry.html>>

Huawei is currently not only the largest telecom equipment manufacturer in the world by revenue, but also competes with top-tier multinational firms, such as Ericson, Cisco, and Nokia in supplying latest technologies. In comparison, the achievements of Chinese semiconductor companies made are relatively limited. It should be recognized that China is only nation being able to break into the high-entry-barrier semiconductor industry with self-sustaining business operations since the late 1990s. Despite the US government's view that the Chinese semiconductor industry as the biggest threat to the dominance of US firms (PCAST 2017), the leading Chinese semiconductor manufacturer, Semiconductor Manufacturing International Co. (SMIC), is only one tenth of the size of the largest international foundry, TSMC, and lagging at least one-generation behind the latest product and manufacturing technologies.

In addition to cross-case variations in innovation outcomes, there are important within-case variations in terms of how each of the two industries evolved over time. In the telecom equipment industry, today's leading firm Huawei started when the Chinese industry emerged in the 1980s, became one of the four leading firms in the 1990s, and was a clear industry leader in the 2000s. ZTE, the main competitor of Huawei, was already a follower in strategy and technology in the 2000s. To examine innovation pathways in the telecom equipment industry, it is sufficient to examine the trajectory of a single company Huawei. And the most important within case variation is how Huawei's innovation strategy co-evolved with industrial policies and changing conditions in market and global industry.

In the semiconductor industry, the domestic industry leadership changed twice in the course since the 1980s. The state-owned Huajing Group emerged as a domestic leader in the newly created market in the late 1980s, which was replaced by a Sino-Japan joint venture Huahong in the mid-1990s. The current industry leader SMIC was an international startup with mixed ownership

started in early 2000s. The changing industrial leadership reflect that the dynamic adjustment of industrial policy and business strategies occurred through profound reorganization of the Chinese semiconductor industry. To examine innovation pathways in the semiconductor industries, it is necessary to analyze the co-evolution of industry policies and changing forms of industrial governance and organizations. Thus, not only current industry leader (i.e. SMIC) but also previous leaders (i.e. Huajing, and Huahong) are investigated in order to understand how the co-evolution took place.

### *2.5.3 Data Collection*

My main data source is semi-structured interviews with managers of the firms or units, government officials, and industry experts (including academics, venture capitalists, journalists, researchers at industry associations and other intermediary agencies, and managers from rivalry firms). The primary interview data is complemented by additional data sources such as shorter, informal interviews and conversations, on-site observations, and archival data for data triangulation as suggested by Eisenhardt (1991) and Yin (2009) to increase validity and robustness of the findings (Denzin, 1970).

The primary data source is a total of 54 semi-structured interviews conducted between May 2012 and April 2017 (See Appendix for a list of interviewees). The interviews were “semi-structured” in the way that they allow the interviewee to speak freely on topics in which they had experience and expertise. Each interview was structured around topics, but greater emphasis might be given to a particular topic and parts of company history depending on the expertise of the interviewee. Unlike an oral survey with specific questions that are asked of each interviewee, the



theme-based semi-structured interview approach allows the researcher to gain insights from the areas where the interviewee has the most knowledge. The interview lasted from one to one and a half hours, and mostly were conducted in Mandarin Chinese in which the participant usually has the highest level of comfort. In a few cases that the interviewee is an English speaker, I conducted the interview in English. Concerning the context of the Chinese political and business environment for field research, all interviewees were guaranteed anonymity.

Interviewees were selected using public records of their firms. I approached the interview targets through emails, phone calls, introduction by mutual contacts, or in the case of large organizations through gatekeepers of the organizations such as public-relations managers. Interviewees were also selected through contacts made at conferences, industry and trade association meetings. In order to create a large pool of critical and knowledgeable interviewees, a “snowball” approach was adopted. In each interview, the participant was asked to recommend other contacts. A potential risk in this approach is the bias of the interviewees who are likely to only introduce those with whom they agree or have good relations. To mitigate this risk, I triangulated my interview data through other primary and secondary sources.

Most interviews were documented as written notes as the presence of recording devices generally discourage Chinese interviewees to disclose valuable information. However, in the case of interviews with Huawei executives, all interviews were recorded by accompanying managers under Huawei company policy and later I was given permissions to make transcriptions from the recordings on Huawei campus.

My second source of data is informal conversations and on-site observations. In studying the semiconductor industry, I spent the summer of 2012 at Shanghai’s Zhangjiang High-tech Park. Zhangjiang is the major semiconductor and integrated circuit (IC) cluster in China. It hosts the

headquarters of SMIC, Grace Semiconductors, and Huahong-NEC<sup>4</sup>, the three largest domestic semiconductor foundries in the 2000s, as well as hundreds of large and small IC design houses. During my stay, I visited the campus of SMIC, attended several semiconductor industry conferences, seminars, and informal gatherings of managers, engineers and entrepreneurs. A brief follow-up visit was conducted in the summer of 2015. In studying the telecommunication equipment industry, I visited Huawei headquarters and campuses in Shenzhen and Dongguan three times in August 2014, July 2015, and April 2017. The 2015 visit was a month-long on-site interview and observations at Huawei headquarters in Longgang, Shenzhen. In addition to formal interviews with Huawei executives, I visited Huawei factories in Dongguan, had informal conversations with Huawei employees, contractors, and suppliers, and engaged in discussions at company-organized industry conferences.

There is a total of 25 informal interviews with written records. Among these interviewees, six worked for central government agencies, nine worked for local government agencies, and the rest are from the business sectors. These conversions typically lasted from 20 minutes to an hour, and were recorded as summary notes after the meetings. The reason to conduct informal interviews, especially with government officials, is that these interviewees were unwilling to conduct formal interviews but were polite enough not to refuse meeting requests when I was introduced by mutual friends.

A third source of data – archival data – is used to provide additional information gained from interviews, especially in reconstructing the history in the 1990s, and for validation and mitigation of recall bias (Huber and Power 1985). In studying the semiconductor firms, two

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<sup>4</sup> Huahong-NEC and Grace Semiconductor was merged in 2010 to form Huali Semiconductor.

memoirs from senior government officials and policymakers were especially useful in reconstructing the history in the 1990s. One is the memoir of Hu Qili (胡启立), former Minister of Electronic Industry and head of Huahong-NEC. The memoir is on project records from Project 909 and Huahong-NEC, published under the title “Road to Chips: Records from Ultra Large Scale Integrated Circuit Project 909” ( “芯” 路历程： 909” 超大规模集成电路工程纪实) in 2006. The other is an industry history compiled by Wang Yangyuan, co-founder and former Chairman of SMIC and professor at Chinese Academy of Sciences with co-author Wang Yongwen, titled “China’s IC Industry Development Path: From a Big, Consuming Nation to a Strong, Industrial Nation” (我国集成电路产业发展之路： 从消费大国走向产业强国) published in 2008. There are more public records on the semiconductor industry since the mid-2000s, providing additional data for analysis. PriceWaterhouseCoopers, a consulting firm, publishes an industry analytical report titled “China’s impact on the semiconductor industry” since 2004 and updated annually. SMIC is a public traded firm listed on New York Stock Exchange, publishing annual reports and various SEC-required filings on its company websites. In studying Huawei, the company gave me permission to access annual reports and the internal company magazine “Huawei People” (华为 人), which provides data on records of major events and details of internal and external company representations.

## **CHAPTER 3. INNOVATION IN THE CHINESE CONTEXT**

### **3.1 Chapter Introduction**

In this chapter, I consider the influences of state, market, and globalization factors on the emergence of innovation pathways through an analysis of Chinese development at the macro level. The analysis of national-level institutions and processes is useful for two reasons. First, this analysis provides backgrounds for industry- and firm-level analysis in case studies in the following chapters by profiling the state, market and globalization institutions in the Chinese environment. Second, the dynamics of economic development and institutional changes are often not directly determined at industry or firm level. As scholars of National Innovation Systems have long pointed out, law, customs, routines, and other institutions governing the behaviors of firms and organizations in the innovation process are usually determined by actors at the national level. In China, such actors might include industry ministries, government research institutes, state-owned banks and other powerful national-level organizations that operate on their own logics and policies. In short, the macro-level analysis of Chinese development complements detailed industry- and firm-level studies by providing an understanding of the overarching structural forces and institutional processes.

My analysis of Chinese development and institutional process focuses on the post-reform period, that is the development after the Reform and Opening-up in 1978. While I concede that the legacy of socialist planned economy practiced can have influences on the innovation pathways unfolding today by providing resources to some industrial and innovation activities and placing restrictions on others, I will only discuss such legacy resources or restrictions without going into details of the institutions under which these legacies were generated. Instead, my analysis

emphasizes the details of the contemporary Chinese market economy institutions, which are characterized by strong government intervention, an open economy and competitive markets, and the co-existence of state-owned and non-state-owned businesses.

In the following of the chapter, I profile the state, market, and globalization institutions, discuss the interactions of two or more sets of these institutional factors, and highlight the influences of the institutional settings on the operation of different types of forms.

## **3.2 The Roles of State, Market, and Globalization in Chinese Development**

### *3.2.1 Roles of the State*

The state has extensive, if not controversial, roles in shaping innovation pathways in China. On one hand, in the West, the Chinese state has been portrayed as a monolithic, static entity with unchallenged controls, relentlessly pursuing technological advantages for the nation through strategic planning and willing to succeed its techno-nationalism vision at the expense of foreign players (McGregor 2010; D'Aveni 2012). On the other hand, critics of Chinese state intervention point out state control over technology and finance and bureaucratic meddling on corporate affairs have led to corruption in the government, inefficiency in state-owned enterprises, an educational system stifling creativity, and discrimination against non-state companies, all of which impede China's innovation potentials (Pei 2006, Huang 2008). The disagreements in the literature, to some extent, show how multifaceted roles of the state are. In this study, I focus on the government-business relations at the level of industrial firms, and I consider the roles of the state in three essential aspects of innovation pathways: the influence on firm governance, government provision of S&T resources, and financing of ventures.

First, the Chinese state can influence innovation pathways through permitting (or not permitting) different forms of corporate governance regimes and ownership. As a legacy from the socialist planned economy, the establishment of autonomous non-state firms independent from state control is a recent phenomenon since the reforms in the late 1970s. The Chinese communist party only quietly withdrew its position of maintaining a SOE-majority economy by the end of the 1990s. Today, the state allows the co-existence of a variety forms of corporate ownership. Among leading high-tech firms, Lenovo and ZTE are spinoffs from Chinese research institutes or SOEs, with the latter still holding share. The newer breeds such as Alibaba, Tencent, and Xiaomi are private startups, but many of them have mixed ownership with state institutions and foreign shareholders.

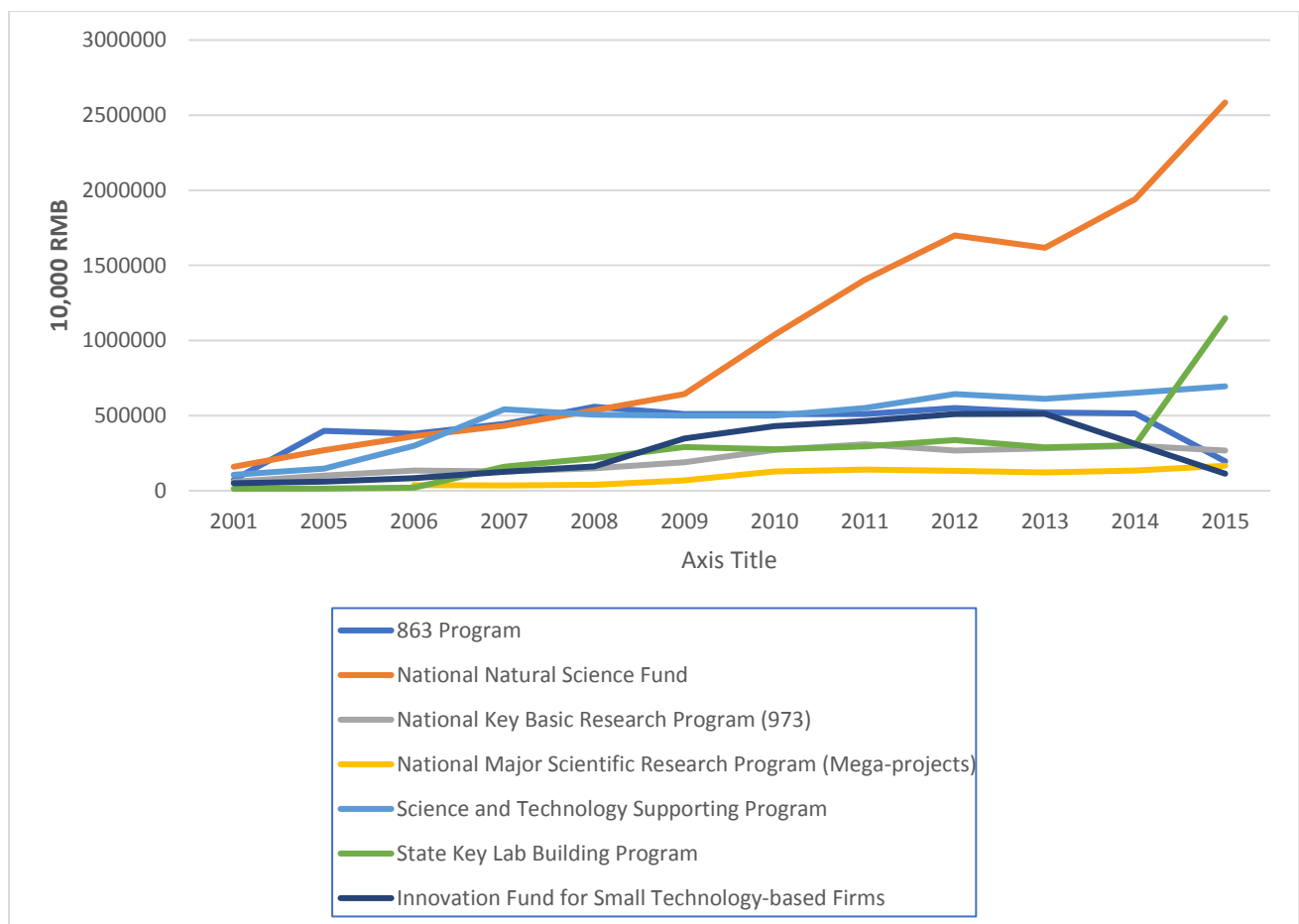
Strategic autonomy of business enterprise, a basic condition for innovation allowing the formulation of independent strategy, should not be taken for granted in the Chinese context. Rather, the allowance of autonomous non-state firms is contingent on the reform process and industrial policy. There is considerable difference among sectors. The Chinese reform is gradual and the timing to reduce state control over key industrial enterprises vary significantly depending on the state's perception of strategic importance of the industry and readiness of domestic firms to compete with MNCs. The process is also hardly linear, involving back and forth in policy directions. For instance, since the Great Recession of 2008-09 and subsequent government stimulus spending, the Chinese government favored SOEs over non-state firms in industrial policy and finance and increased ownership and control in strategic industries. Such policy has been criticized as “Guo Jin Min Tui” (国进民退) or literally meaning “advance of the state and retreat of non-state” (Breslin 2011).

Second, the Chinese government is main investor in the country's S&T resources, especially in long-term, high-cost, and high-risk projects public in nature. Such investments span from ambitious military and space programs, to the development of infrastructure technologies, to educating a deep pool of S&T human resources, which can lay a foundation for innovative firms. However, when it comes to how government-invested S&T resources can be accessed and commercialized by firms, the roles of the government have not been consistent.

There have been two waves of large investment in S&T resource and exploitation in China. The first wave was the creation of a self-sufficient Soviet-style S&T system in the 1950s and 1960s. Commercial exploitation of the legacy S&T infrastructure reoccurred only in the 1980s and 1990s when universities and government research institutes were forced spin off companies to generate incomes under decreased state funding (Lu 2000; Zhou 2005, 2008). These spinoffs include some non-state information technology giants, including Lenovo and Founder, and most of Chinese biotechnology companies. This period of spinoffs ended in late 1990s when government restored and increased funding for research and a growing scrutiny of dubious uses of public fund for commercial endeavors by research institutions.

The second and current surge in S&T investment is part of the "Indigenous Innovation" campaign, reflected in data as a substantial jump in government funding to almost all major S&T programs since 2006 (Figure 3). A central piece of the indigenous innovation policy is 16 national S&T mega projects funded in 2006, spanning from space program to nuclear fusion to civilian aircraft to new drugs. The mega projects are intended to address the perceived weakness of Chinese companies in investing in long-term and high-risk R&D projects. The mega projects are administrated through a top-down system, guided by top government leadership, coordinated by planning agencies and financial ministry, and carried out by industrial ministries in their fields.

This heavy-handed approach is regarded as China's return to techno-nationalism after two decades of marketization and globalization (Chen and Naughton 2016). Another trend is, since 2009, S&T funding allocated by National Natural Science Fund, a relatively young funding agency modeled after the National Science Foundation of the U.S., grew dramatically, while other programs funding has been stabilized (except for a dramatic increase on the State Key Lab Building Program in 2015). It indicates that the state has consolidated newer S&T funding under the more open and competitive allocation process of National Natural Science Fund, and more government funding is allocated towards basic and applied research in universities and research institutes.



**Figure 3 Funding to China's Major S&T Programs (2001-2015)**

*Source: China S&T Statistical Yearbook, 2006-16*



There is a significant difference in the organization in the recent S&T projects, especially in relations to the business sector. Unlike policies from previous eras, participation of enterprises is encouraged and commercialization of technology is a key measure of success. Research consortia, a practice borrowed from Korea, Japan, and the US, are increasingly used in S&T projects with industrial settings such as those in telecommunication, semiconductor, and electric vehicle. Unlike its foreign counterparts, Chinese research consortia has the government as key coordinator, forming R&D teams from industry, university and research institutes in carrying out the research, development, or implementation of targeted technologies. Large non-state companies such as Huawei in telecommunication and SMIC in semiconductor foundry might involve in consortia, but overall the consortia are led by primary SOEs and government research institutes (Liu and Peng 2011).

The recent dramatic increases in government R&D funding has not changed the country's strong favor of near-commercialization development activities in the distribution of R&D activities. Comparing to the OECD countries, China has the highest ratio of R&D expenditure on experimental development, which is the type of R&D activities directly applying existing knowledge and skills in generating new or improved products and processes, and the lowest on basic and applied research (Table 2). Even compared to itself historically, China has the highest ratio of experimental development funding since 1995 when the government started to collect such data. Since more than three quarters of R&D in China is undertaken by the business sector, the state's investment in basic and applied research might be only playing catching up at this point.

**Table 2 International Comparison of R&D Funding (%) by Types of R&D Activities**

Country	Year	Basic Research	Applied Research	Experimental Development
China	2015	5.1	10.8	84.1
Japan	2013	12.6	20.9	66.5
Korea	2013	18.0	19.1	62.9
United States	2013	17.6	19.9	62.5
Denmark	2012	18.3	27.6	54.1
Austria	2011	19.0	35.1	45.9
Australia	2008	20.1	38.7	41.2
France	2012	24.2	37.4	38.4
United Kingdom	2012	15.5	47.0	37.5
Czech	2012	30.0	36.3	33.7
Switzerland	2012	30.4	40.7	28.9
Italy	2012	25.3	48.9	25.8

*Source: China S&T Statistical Yearbook, 2016*

Third, the heavy-handed, top-down intervention from the central government has been complemented by more flexible and collaborative regional and local governments. Regionalism in China, in the form of business-oriented local government and fierce inter-regional competition, has been credited as a driving force of economic growth in the post reform era (Granick 1990; Naughton 1994, 1995; Huang 1996; Shirk 1993; Oi 1999). To foster growth, local governments cultivate close ties with local firms, regardless of their ownership. In regions without the presence of strong SOEs, local governments such as in Guangdong and Zhejiang especially promote private entrepreneurship and non-state sector. Chinese local governments provide various forms of subsidies, loans and cheap lands to industrial firms, build industrial parks and startup incubators, and many of them invest venture funds in entrepreneurial firms. Some scholars have argued that local governments have supplied an important public good for high-tech firms – the protections of property rights especially of those intangible assets (Segal 2003).

In terms of innovation pathways, while the central government in Beijing is eager to push for long-term, risky R&D projects, local governments are more interested in innovation and

entrepreneurship that can generate industrial growth and employment. Breznitz and Murphree (2011) give credit to the pragmatism of Chinese local government, arguing that it allows China to capture growth opportunities through incremental innovations and generate lots of wealth and employment. Yet, overemphasizing the pragmatism would underestimate the willingness of Chinese local governments to take risks. There are growing evidences that the local governments are betting heavily on emerging industries. For instance, several cities in the Jiangsu Provinces strategically cultivated the solar photovoltaic industry and incubated important new firms such as Suntech, in the early 2000s even when the central government preferred wind turbines over solar panels in planning (Hopkins & Li, 2016)

The downside of regionalism, however, is whether the roles of local governments can slide into local protectionism and discourage innovation. There are prolonged overcapacity issues across many industrial sectors in China, often because the rationalization policies of the central government are countered or watered-down by the instincts of local governments to preserve local industrial capacity as sources of employment and revenue. Such local protectionism only delays the “creative destruction” process by feeding bank loans and subsidies to low-performing enterprises. In emerging industries, competing regions create a bandwagon effect in which local governments rush into investing in similar industries at the same time, resulting in cutthroat competition among new business and less resources for innovation (Li, 2016).

In short, the Chinese state has enormous and multifaceted roles in shaping innovation pathways. The state shapes the governance structures of business enterprises, allowing autonomous non-state firms emerging unevenly across industrial sectors. The government invests heavily in S&T infrastructure and human resource, creating capacities for innovation and potential indigenous sources of technologies as an alternative to foreign ones. However, access to state

resources is uneven and subject to industrial policy, which favors state-owned enterprises and more recently, large non-state-owned firms. The pursuit for long-term, risky R&D projects has been complemented by local governments, which favor innovation and entrepreneurship that generate profits and employment quickly.

### *3.2.2 Globalized Production*

The level of embeddedness of China in globalized production sets the Chinese experience apart from earlier industrialization of Japan and the United States. China began to experiment export promotion policies in the late 1970s through establishing a set of export processing zones (officially named “Special Economic Zones”) along the southeast coastal lines to attract foreign direct investment (FDI). The initial goals were not about technological development, but to create jobs, reduce poverty, and earn foreign currencies. In the 1980s and 1990s, investment from ethnic Chinese in Hong Kong, Taiwan, and Southeast Asia, estimated to account almost two thirds of FDI China attracted during the time, brought labor-intensive export production to the country (Lever-Tracy and Ip 1996). Since the mid-1990s, sources of FDI diversified to include the US, Japan, South Korea and European countries. Partly driven by the policy to attract high-tech through lucrative joint ventures between state entities and foreign firms, FDI had flown to more capital intensive and technologically sophisticated projects. By 2009, China had become world’s largest exporter with trade accounting for more than half of its GDP (IMF 2011).

Comparing to its East Asia neighbors, China is a rare case of a large country relying extensively on FDI. In the past, Japan and Korea, the two larger countries, had intentionally and protected domestic markets fiercely. Only smaller economies, especially Singapore and to a lesser

extent Taiwan, relied heavily on FDI. In the case of China, a high level of FDI is a result of both foreign firms in China engaging in export processing and foreign firms targeting domestic markets (Brandt and Thun, 2010). Although foreign firms in China face a variety of restrictions, they can still put enormous competitive pressures on domestic firms with their superior capabilities, and in some sectors, aided by policies to attract FDI. Indeed, some scholars have argued that the set of policies adopted in the 1990s is systematically biased in favor of foreign firms (Huang 2003). Since the WTO accession in 2001, China is far more open than its East Asia neighbors when they were at similar levels of development.

The high levels of FDI in China during its growth from the 1980s coincided with a larger trend: the globalization of production. Since the late 1960s, global production networks (GPNs) emerged as increasing levels of specialization in vertical production relations and dispersion across geographical borders. Many factors had driven such development, including liberalization of international trade, advances in container ship transportation that drastically reduced transport costs, and the development of information technologies that reduced communication costs and enabled codification of design information in digital forms thus allowing the further separation of design and manufacturing. One result of the development of GPNs is the rise of intermediate goods trade and the separation of technological sources and productive activities. As some scholars point out, in the world of GPNs, “the mosaic of specialization an intermediate goods flows that make up distributed production systems and global value chains (GVCs) means that domestic capabilities and development cannot easily be... linked to domestic sources (Whittaker et al 2010, p.11)”. The other result is that multinational corporations tend to be most capable players in the GPNs to control the value chains through occupying core nodes and capture the parts with most profits. Some scholars even argue that, “The main purpose of these networks is to provide the flagship

with quick and low-cost access to resources, capabilities and knowledge that are complementary to its core competences” (Ernst and Kim 2002, p. 1420). Others have found that multinational corporations have advantages in both buyer-driven and producer-driven chains. In buyer-driven chains, the core competences are marketing, sales, and distributions. In producer-driven chains, the core competences are technology and design. Firms from developing countries are generally weak in those types of capabilities (Gereffi 1999; Humphrey & Schimitz 2002).

GPNs provide China with opportunities to master manufacturing and learn from the flows of knowledge within the networks. By becoming subcontractors of leading firms in the GPNs, Chinese companies can theoretically follow the established learning sequence of learning from contract manufacturing to own brand manufacturing. Indeed, Breznitz and Murphree (2011) document a successful case of uninterruptable power supply (UPS) manufacturers in the Pearl River Delta region which followed such a path. The local UPS firms started as subcontractors in the GPNs, and steadily upgraded capabilities in software and interface design to approach global standards. Through a set of incremental innovations in design and manufacturing, these manufacturers now constitute the world’s largest and most advanced UPS producing cluster. While they continue to make OEM products for multinational firms, they have started to establish their own brands in China. Breznitz and Murphree (2011) argue that such strategy prevails in companies assembling ICT hardware in the Pearl River Delta region.

Yet, many more see that because of the decoupling of technology and production, China has become an important site of global production without mastering the underlying technology. Steinfeld (2004) argued that Chinese firms are stuck in the low-value added segment in their commodity manufacturing for the global markets. An International Monetary Fund (IMF) report found that, using OECD data, foreign contents accounted for almost half (48.5%) of total value

added of Chinese exports in high tech industries in 2005. Using different data sources, Wei (2012) arrived at similar findings. He calculated that the share of value-added from domestic sources is 60.6 percent in Chinese gross exports in 2007, but the share of domestic sources in high-tech industries is only in the 30 to 40 percent range. Such dependence on foreign technologies is especially unacceptable in the eyes of Chinese policy makers who set goals for becoming an innovation power.

The other side effect of the GPNs is that while the GPNs lower the entry barriers of some segments by detaching technology from manufacturing, GPNs might have simultaneously increased barriers in other segments of production. These are the segments that favor economies of scale and control over technology standards, and the de-verticalization of production creates a “winner-takes-all” situation where a few giants might supply the whole world market. One such example is the semiconductor fabrication industry, where one company, Taiwan Semiconductor Manufacturing Corporation (TSMC), has decisive lead in both technology and capital in the fabrication of mobile phone IC chips. It literally takes a nation’s wealth to compete with such a giant, as shown in the experience of GlobalFoundries, a firm backed by Abu Dhabi’s sovereign wealth fund, struggling to maintain a Number 2 position in the industry. These sectors are extreme examples of the producer-driven supply chains, but they are the type of industries critical to innovation success in the global economy.

In short, China is more embedded in globalized production than previous successfully industrialized nations, especially those with larger economies. Manufacturing for the world market and allowing a high level of FDI at home create both opportunities and obstacles in innovation pathways. On the upside, GPNs provide channels to pursue the established learning sequence of reversed product cycle, and ready to access capabilities in the forms of intermediate goods for

Chinese companies. One the downside, Chinese companies can be stuck in the lower-value-added segments of manufacturing activities, continuing to rely on technologies from abroad, and finding it even harder to break into segments requiring core competence in the GPNs.

### *3.2.3 Expanding Domestic Markets*

A vast and growing domestic market allows China to pursue different innovation pathways than previous East Asia newly industrialized economies (NIEs). This enormous internal market consumes more than 80 percent of industrial output in China, and growth in manufacturing sectors has averaged more than 15% every year over the last two decades (Brandt and Thun 2016). Today, China is the largest market in the world in a wide range of manufacturing goods from steel to mobile phone to machine tools and to semiconductors. This large and growing internal market not only creates dynamics of its own, but it also becomes a focal point where the actions of government, domestic companies, and foreign players intersect.

The Chinese government has consistently sought to leverage the country's large internal market to accelerate technology development. A dominant industrial development strategy in the 1980s and 1990s was the policy of “trading market for technology” (TMFT). The idea of TMFT was pitched by industrial bureaucrats soon after the reform, and the government embraced it as a state policy in 1984 (Xia and Zhao 2012; Feng 2011). The rationale of the TMFT policy was to grant access of the Chinese market to foreign companies in exchange for the transfer of advanced technologies to China. A typical TMFT project involves establishing joint ventures between leading SOEs and foreign firms, in which the foreign partner provides targeted technologies, some capital, and managerial expertise, while the Chinese partner contribute facility, personnel, and



sales channels. To attract foreign firms to participate in TMFT projects, many joint ventures were given guaranteed market shares. For example, the joint venture between Shanghai Auto and Volkswagen of Germany was given the monopoly of the Chinese passenger car market between 1985 and 2000 (See Feng 2016). The policymakers expected that the Chinese companies, in addition to absorbing targeted technologies, would learn from their foreign partners in daily operations to accumulate the experience and knowledge to manage modern high-tech enterprises. The TMFT policy and projects spanned a range of industries strategically targeted by the state, from automobiles to telecommunication equipment, until restrictions for foreign entries in most manufacturing sectors were gradually removed by the accession to WTO.

The TMFT policy and projects never met the policy makers' expectations in fostering domestic innovation capabilities by building on transferred technologies. Part of the reasons for TMFT failures is badly designed incentive structure and lack of autonomy in the SOEs and their joint ventures. By participating in TMFT projects, the SOEs were functioning more like task forces in meeting technology assimilation targets set by the state, stripping away independent strategy making and in many cases hollowing out their own R&D projects. To make it worse, the guaranteed market access in TMFT is made for a fixed period of time (often ten to twenty years in the automobile industry) rather than being contingent on continuous or accomplished technology transfer. Under such arrangements, neither the foreign partners are compelled to make further transfers nor the Chinese partners are motivated to seek upgrades, as long as the state-guaranteed market is profitable (Xia and Zhao 2012; Feng 2016). The other reason for failures is the changing nature of technological development under globalized production. When planning for TMFT, the Chinese policy makers still have the mentality of import substitutions strategy, and the whole policy was targeting increasing levels of production localization with the assumption that China

would acquire embedded technologies through mastering production. Unfortunately, such assumptions are increasingly unreliable under GPNs, as manufacturing has become decoupled from R&D, design and technology development (Whittaker et al 2010).

One way to measure the intensity of learning from foreign technology is to look at the efforts and spending on assimilating technology compared to importing technologies. Assimilating imported technologies involves costs in training workers, investing in complementary equipment and facilities, process development costs, and so on. It is reported that in South Korea of the 1980s, which was a successful catching-up and learning economy, the ratio of expenditure on assimilating technology to importing technology was as high as 2:1 (KOITA, various years). Using Chinese government statistics, Zhou and Liu (2016) calculate such a ratio in China. They find in 2002, barely 0.1 RMB yuan was spent on assimilating technology for every yuan spent on importing; the ratio was only 0.57:1 for SOEs in 2012 (Zhou & Liu 2016: 42-43). Using the newest data from China S&T Statistical Yearbook, I calculated the ratio for various types of Chinese firms in 2013 – 2015 (Table 3). Unfortunately, the data reported by the Ministry of Science and Technology are inconsistent over time, especially in 2015. There are also questions of whether assimilation spending reported by Chinese agencies is comparable to the Korean ones, since the Chinese seems to assign assimilation costs related to reverse engineering and process alteration to generic R&D expenditure. Nevertheless, the data show, among different ownership types of firms, non-state domestic firms spend slightly more on assimilation than state owned firms, while foreign invested firms, including Sino-foreign joint ventures have very low ratios of assimilation to importation costs (except for 2015 where data is inconsistent with previous years). While it should not be overstated, especially given the data quality, the assimilation to importation ratio shows that the

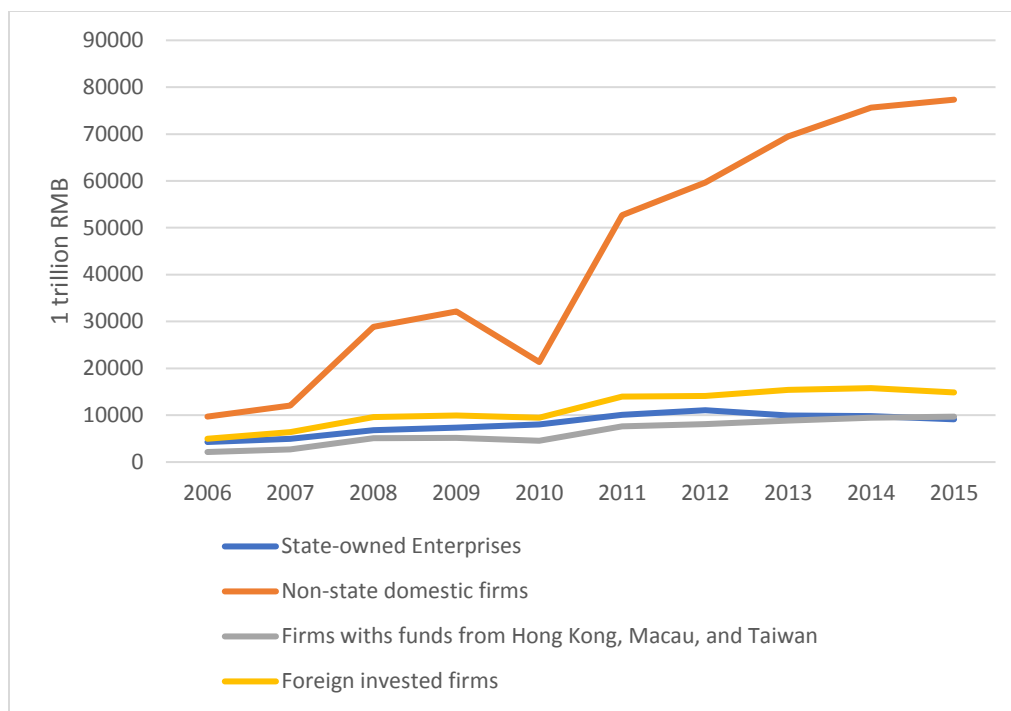
joint-venture venue might not be an effective method to integrate imported technology and to create improvement and adaptations.

**Table 3 Ratio of Expenditure on Assimilation to Importation of Technology by Ownership Types of Firms (2013- 2015)**

	2013	2014	2015
State-owned enterprises	0.56	0.3	0.075
Non-state domestic firms	0.61	0.62	0.36
Firms with funds from Hong Kong, Macau, and Taiwan	0.16	0.31	0.35
Foreign invested firms	0.22	0.19	1.57
All firms	0.38	0.36	0.26

*Source: China S&T Statistical Yearbook 2014 – 2016; Author's calculation*

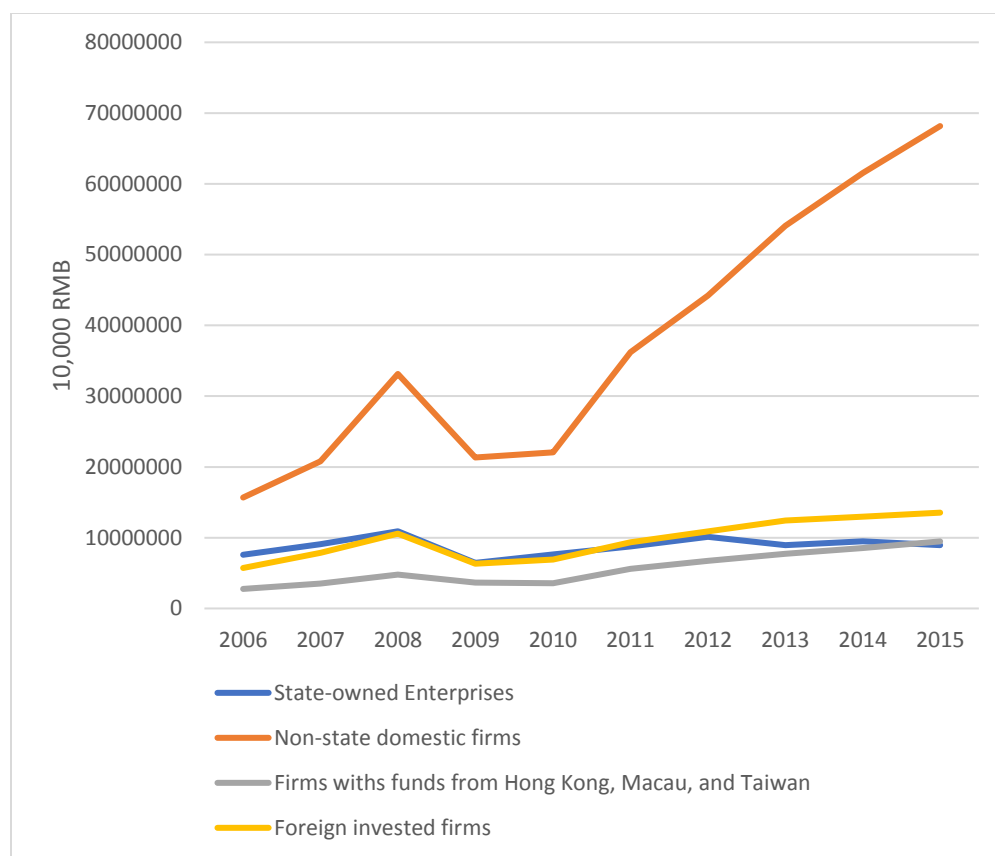
Compared with the state sector, Chinese non-state companies are much nimbler in adapting to the new reality of technological development. Using Chinese government statistics collected from 2006 to 2016, it is easy to show that the non-state domestic sector, including private firms and firms with mixed ownership, is taking the lion's share of industrial output, R&D spending, and innovation output in the Chinese economy while the state-owned sector, including state-owned enterprises and state-owned firms, has a declining or stable share (Figure 4, Figure 5, Table 4). Figure 4 shows that non-state-owned firms are the biggest contributors to China's industrial output and they have the highest growth rate. While the non-state sector was hit hardest in the aftermath of the 2008-09 Financial Crisis, the sector also rebounded quickly to a pre-crisis trajectory. In comparison, the state-owned sector has been declining in absolute terms since 2012. The trend should not be over interpreted, though. The state-owned firms, even though having a decreasing share of GDP, still occupy the commanding heights of the economy, especially in resource-intensive, up-stream industrial input sectors, such as petrochemical, power, mining, metallurgy sectors but also in finance, telecommunication, and transportation sectors (Economist 2017).



**Figure 4 Total value of industrial output by ownership types of firms (2006 – 2015)**

*Source: China S&T Statistical Yearbook 2007 – 2016*

When it comes to innovation activities, the non-state firms have a clear advantage. On the R&D input side, the non-state sector clearly outspends any other types of firms (Figure 5). Such advantage holds true if the R&D expenditure is replaced with other R&D input measures such as the number of scientists and engineers hired, number and size of R&D projects, and size of corporate labs (cf. Zhou and Liu 2016: 56-58). R&D spending by state-owned firms declined since 2012, following a similar trend of industrial output. Surprisingly, the foreign-invested firms and firms from Hong Kong, Macau and Taiwan both steadily increased their R&D spending since 2010, which illustrate increasing incentives and pressures for foreign firms to allocating R&D activities to China, either because of upgraded markets or intensified competition.



**Figure 5 R&D expenditure by ownership types of firms (2006 – 2015)**

*Source: China S&T Statistical Yearbook 2007 – 2016*

Using patent statistics to measure innovation output is tricky, since patented invention might not eventually be transformed into actual novel development. It is also well-known that the incentive for patenting is distorted by patent subsidy in China (Lei, Sun, & Wright 2012; Li 2012). Nevertheless, Table 4 provides a comparative angle of patenting activities by different type of firm ownership in China. Due to data limitation, I look only the latest three years and invention patents, which are the relatively high-quality patents in Chinese patenting system. The data show that the non-state firms have the dominant and expanding share in number of invention patent applications. Foreign-invested firms are active in patenting in China, but their number of filings fluctuates significantly even over a short three-year period, possibly because foreign-invested firms have

more flexibility in deciding the location of filings. Interestingly, the number of invention patent filings by state-owned firms grew steady in this period even the absolute spending on R&D declined. It implies that reform of the state-owned sector continues to consolidate the industry around the strongest state-owned firms.

**Table 4 Invention patent application activities by ownership types of firms (2013 - 2015)**

	N. of patent applications			Share (%)		
	2013	2014	2015	2013	2014	2015
State-owned firms	19080	22277	24116	9%	9%	10%
Non-state domestic firms	139898	166115	174146	68%	69%	71%
Firms with funds from Hong Kong, Macau, and Taiwan	18124	20661	21507	9%	9%	9%
Foreign-invested firms	28044	30872	25919	14%	13%	11%

*Source: China S&T Statistical Yearbook 2014 – 2016*

These indicators show the growing economic strength and innovation capacity of the non-state firms in China. Part of their success could be attributed to strategies to marry the advantage of expanding local markets with the system of globalized production. There are two integrated parts of their strategies: developing marketing, sales and distribution capabilities through competing with MNCs in China, and developing design, technology, and production capabilities through linkages with the global production systems (Zhou 2005, 2008; Brandt and Thun 2010).

Chinese companies, especially leading non-state firms, have been successfully outcompeting MNCs in their home market in a range of manufacturing goods sectors, such as white goods, consumer electronics and telecommunication devices (cf. Zeng & Williamson 2007). In the West, unsuccessful business adventures in China are often illustrated as results of protectionist policies and bureaucratic meddling by the Chinese government. But as I have shown so far, to attract FDI, the Chinese government gave preferential treatments and lucrative joint

venture opportunities to MNCs until at least the mid-2000s. In the setup of TMFT policies, it is the local, non-state companies that have been discriminated against, with far less resources and being restricted to more market segments than SOEs and foreign firms (Huang 2003). On the other hand, there is a growing literature in business strategy addressing how Chinese companies honed their skills through competing with MNCs in their home markets (Gadiesh, Leung, & Vestring 2007; Zeng & Williamson 2007). These literatures, however, tend to attribute the competitive advantages of Chinese companies to low-cost advantages, without an understanding of their sources of innovativeness.

The indigenous companies have insider knowledge of the local markets, and they have developed marketing, sales, and distribution capabilities to transform such understandings into competitive advantages. While MNCs have superior technological and managerial expertise and a global network of resources, they do not have understandings of local preference and culture, and generally lack incentives to develop such knowledge when an emerging market just starts to grow. As Porter (1990) has pointed out a long time ago, there are numerous problems MNCs might encounter when doing business in a foreign market:

“Understanding needs requires access to buyers, open communication between them and a firm’s top technical and managerial personnel, and an intuitive grasp of buyers’ circumstances. This is hard enough with home buyers. It is extremely difficult to achieve, in practice, with foreign buyers because of distance from headquarters and because the firm is not truly an insider with full acceptance and access to fully understand foreign buyer needs and how they are changing, it is a daunting task to communicate them credibly to headquarters” (Porter 1990, pp. 86-87).

To make it worse, many MNCs started their business in China through ties with the government, being invited by the latter with a ready-to-access market (Lu and Feng 2004). Thus, it is not surprising that MNCs in China had a competitive disadvantage when they only sell products designed for advanced countries, pay little attentions to redesign for local preference, and respond slowly to changes in markets. In contrast, indigenous companies must deeply commit to a few unrestricted industries to survive cutthroat competitions. The non-state companies that secured initial success, as in the example of Lenovo studied by Lu (2000), would invest in building a national sales and distribution network rapidly to control the market.

At the same time as securing local market access, the non-state companies build their design, technology, and production capabilities through working with supply chains developed in China as parts of the global production system. There are two approaches documented in the literature, showing the strategy may vary by industry conditions. One approach is to tap into the supply networks and capabilities developed for exporting. Chinese companies take advantage of the presence of export-processing facilities by accessing high-quality component suppliers and contract manufacturers – developed to serve MNCs in the global market – combined with localized design and low pricing to succeed in local markets. Such approach is found in the globalized production systems in ICT industries (Zhou 2008). The other approach is to take advantage of the localization of MNCs' supply chains. To compete in China's low- to mid-end markets, MNCs are pressured to work with local suppliers to lower their cost structures. Chinese companies can access to these local suppliers upgraded by technical assistance from MNCs, and in turn accelerate their own upgrading process. The second type of dynamics has been found in mature industries such as automotive, construction equipment, and machine tools (Brandt and Thun 2010). Interestingly,



these are the same industries that benefit most from China's pre-reform investment in industrialization and TMFT projects that build networks of local suppliers with basic capabilities.

By tapping into the supplier networks and productive capabilities nurtured by the MNCs, Chinese non-state companies accelerate their progress of technological development by focusing on core competence in marketing, distribution, design and technology. The Chinese non-state companies should be credited for their entrepreneurship: by creatively developing and recombining capabilities in the economy, they engaged in innovation in a Schumpeterian sense. However, there are downsides of this model. First, since the supply networks are open to everyone, Chinese OEMs relying on such networks for manufacturing can easily be trapped into undifferentiated competition, unless the company can develop complementary capabilities in marketing and technology. Second, the marketing and distribution capabilities developed in this model are highly contingent on Chinese context, thus it is not likely work well in international markets. Third, this model does not solve the dilemma of decoupled technology and production posed by globalized and modularized production. Accessing MNCs' supply networks does not equate to mastering the underlying technologies. To innovate especially as the Chinese companies are approaching technological frontiers, they must further develop and accumulate core capabilities in design, technology, and manufacturing.

### **3.3 Chapter Conclusion**

In this chapter, I used a variety of data sources, including historical records, statistical data, and existing researches, to analyze macro-level dynamics of innovation activities influenced by state policy, market expansion and globalized production. The analysis shows that there are trends and structural forces driving innovation activities at the national level, including the general process of economic reform, rising incomes, changing national S&T strategies, FDI policies, among others.

The analysis also shows, the emergence of innovation pathways in China is contingent on industry- and firm-level dynamics. Not all industries are created equal. There are vast differences in industrial and innovation policies across industrial sectors, in terms of regulation of entry, provision of public R&D and finance, and access to government-provided resources by different types of domestic firms. These policy differences compound the inherent differences in technology, market structure, and organization of global industry among industries. To better understand the mechanism of the emergence of innovation pathways, I now turn to case studies of two specific industries and their leading firms.

## **CHAPTER 4. THE SEMICONDUCTOR INDUSTRY**

### **4.1 Chapter Introduction**

Innovation occurs in the context of an industry characterized by particular technologies, markets, and competitors. In this chapter, I present a case study of innovation pathways at the industry level: the semiconductor industry in China. The development of a semiconductor industry in China over the last thirty years is a critical case to examine the Chinese model of approaching technological frontiers. There are several reasons that warrant a close examination of the semiconductor industry:

First, semiconductors, including diodes, transistors, and integrated circuits (IC), are technology drivers and value centers in the modern electronics industry. Historically, both Japan and Korea mastered the semiconductor technologies to secure industrial leadership in electronics. As the growth of the ICT industries is central to Chinese development, semiconductor technologies remain critical to China's success in innovation.

Second, semiconductor technology is extremely dynamic and globalized. Over the last thirty years, technological change in semiconductors follows approximately Moore's Law that every two years the performance of integrated circuits will double and price will be halved (Moore 1965). To simply keep up the pace of technological change requires a broad set of skills and capabilities as well as hefty financial investment. While the semiconductor industry was once dominated by integrated device manufacturers (IDM) which design, manufacture, and sell their own semiconductors, today the R&D and production of the semiconductor industry is organized in globalized networks by specialist firms including foundry firms which manufacture based

on 'customers' specifications and fabless firms which have their designs manufactured by foundries. China entered the industry in an age when the process of globalizing semiconductor technology had taken place. Its experience provides a snapshot of how China has brought together a broad scope of knowledge and skills necessary for innovation in a globalized high-tech industry.

Third, the long history of developing the semiconductor industry provides a track record of the evolution of technology policy and business strategy in China. This industry was incubated within the first decade of the People's Republic, but the efforts to closing gap with the technology frontier last throughout the reform era till today. Examining the semiconductor industry case provides ample opportunities to observe the birth, growth and maturing of critical organizational forms for innovation as well as underlying government policy and business strategy.

Researchers studying high-tech industries in China have paid attentions to the semiconductor industry for a long time. During the 1980s, Simon and Rehn (1987) studied the state-owned semiconductor industry in Shanghai to show the bureaucratic barriers hindering innovation and efforts to reform towards a hybrid economy, combining planning and markets. The locus of innovation in the semiconductor industry, however, soon shifted to the foreign-invested and private firms in the late 1990s and 2000s. Some scholars seem the progress in the Chinese semiconductor industry is driven by larger forces of globalization, such as the circulations of talent between the Silicon Valley, Taiwan and China (Saxenian, 2005) and specializing in stages of the global supply chain (Breznitz and Murphree, 2011). Others, while acknowledging the context of globalization, see organizational-level factors as more critical. Fuller (2005, 2016) argues that there is one specific type of firm, which is backed by foreign capital but managed by Chinese talent, that contribute most to technology development. In my previous studies, I analyzed in detail the technology strategy and enterprise governance in both innovating and stagnant Chinese

semiconductor firms, concluding that the organizational factors in innovative firms are at least as important as market forces (Li 2011, 2016).

There are three dissertations in English and Chinese that have studied the Chinese semiconductor industry extensively. Chen (2005) studies the policy process of formulating semiconductor industrial policy in the 1980s and 1990s as a window to examine the role of elites, institutions, and consensus in Chinese politics. Fuller (2006) uses the Chinese semiconductor firms in the 1990s and early 2000s as an example to advance an argument relating sources of finance and types of ownerships to a firm's contributions to Chinese technology development. Mays (2013) specifically re-constructed a history of this industry in the 1990s to examine organizational changes that connect the old state industry in the 1980s to the new global industry in the 2000s. While these studies provide rich materials to this study, they have very different research questions, and none of them predicted the industry's current model of drawing from both global linkages and domestic markets to advance technology.

In this chapter, I will build on the previous studies to discuss the government policies and business strategies of the Chinese semiconductor industry to close the gap with technological frontiers. The focus of this study is the process of creating firms leading domestic technology development. Compared to previous studies, this chapter presents a long-term historical account of China's major pushes into semiconductor since the 1980s to today, which allows for insights into the evolution of policies and strategies.

The rest of this chapter is organized as follows: I will first profile the history of the Chinese semiconductor industry and the processes of creating its major industrial firms. Then I will use the empirical evidence presented to test existing theories and clarify several myths and understandings of the development of this industry, such as the roles of state finance, technology transfers, and

product cycles. Then I present an alternative view on the opportunities and processes of technology development and capability accumulation through the lens of innovation pathways.

Before I dive into the case studies, a brief overview of semiconductor industry structure and technology characteristics is necessary to understand the context of the study.

**Changes in the semiconductor industry structure.** The production of semiconductors could be part of an integrated business operation in a larger enterprise which manufacture semiconductors as components for its end products, or as a separate business to produce semiconductors for clients. In the latter case, such a chip maker is called a merchant foundry. A merchant foundry that performs all three main steps of design, fabrication, and PAT (packaging/assembly/testing) of semiconductors is called an integrated device manufacturer (IDM). Further vertical disintegration in the industry in the 1990s led to even more specialized firms focusing one particular step: a manufacturing firm specialized in semiconductor fabrication according to designs by clients is called a pure-play foundry; a semiconductor design house outsources all of its manufacturing operations to the foundries is called a fabless semiconductor company or a fabless design house. The key three steps in the semiconductor value chain is illustrated below:

**Design → Fabrication → Packaging/Assembly/Testing**

**Measurements of semiconductor technology.** Semiconductor technology can be measured in two ways, by lithography node or by wafer size. Lithography nodes measure the minimal size of features on an integrated circuit (IC), thus is a good measure for both semiconductor design and fabrication process technology. In the 1990s, lithography nodes were typically measured in microns (1micron or 1 $\mu$ m =1/1000 millimeter); by the late 2000s, the

semiconductor technology has advanced to the scale of nanometers ( $1\text{nm}=1/1000$  micron). Another measure of semiconductor manufacturing technology is the wafer size, which refer to the size of silicon wafer used for semiconductor fabrication in the foundries. More advanced fabrication lines use larger sized wafer to offset the higher costs of advanced node technologies. The leading foundries transited from 8-inch wafer lines to 12-inch lines in the 2000s, but the transition to 16-inch wafer has not started by 2017.

## **4.2 The Evolution of Semiconductor Industry in China**

### *4.2.1 The Origin of the Industry*

China was among the first handful of nations developing semiconductor technologies. In 1956, the Chinese government's "March Towards Science" (向科学进军) campaign identified semiconductor as a key priority for China's future. In the 1950s, the Chinese Academy of Sciences held seminars for overseas returnee scientists to lecture semiconductor theory and manufacturing, and five elite Chinese universities, including Peking University, Fudan University, Jilin University, Xiamen University and Nanjing University, established semiconductor physics departments. As early as in 1957, the first class from Peking University's semiconductor physics department graduated and many later took leadership positions in government, industry, and academia, including Wang Yangyuan (Chairman of SMIC), Xu Juyan (Chief Engineer of Huajing), and Yu Zhongyu (Chief Engineer of Ministry of Electronics Industry) (Wang and Wang 2008:291).

In 1965, Chinese researchers developed their first integrated circuit (IC), only seven years after the IC was invented by Texas Instrument in 1958, earlier than Korea or Taiwan. Unfortunately, the Cultural Revolution from 1965 to 1975 disrupted the progress. In the aftermath,

China had a small and backward semiconductor sector, consisting dozens of state-owned factories structured through a centrally planned economy. The main products of these factories were simple diodes and transistors, a basic type of “discrete device” semiconductors that are not qualified as advanced microelectronics. State labs, including the Chinese Academy of Sciences (CAS) Institute of Semiconductors and regional semiconductor labs carried out R&D activities.

China’s state semiconductor industry before the reform suffered from prevailing problems of a planned economy, such as bureaucratic and hierarchal organization structure; a incentives system based on meeting production quota resulting in inefficient use of materials and waste and disincentive for profit and innovation; organizational separation of R&D and production; rigid career path and lack of incentives for individuals, among others (Walder 1995; Harding 1985; Evans 1995; Kornai 1992; Lardy 1998; Naughton 1995; Rawski 1994). However, there are three issues particularly relevant to the semiconductor industry. First, the separation of R&D and manufacturing by bureaucratic barriers is inefficient for technology development and transfers. State factories often manufactured designs that labs developed ten to fifteen years and they had difficulties in retooling for newer designs (Simon and Rehn 1987, p.269). Second, the state factories suffer from poor management models and weak worker skills. In the 1980s, Chinese semiconductor factories had yields as poor as 20 to 40 percent—this meant that 60 to 80 percent of the semiconductors produced were defects, comparing to internationally competitive Japanese manufacturers with yields higher than 70 percent (Simon and Rehn 1987, p.268). Finally, the independent development of semiconductor technology is not only slow but also isolated from the technological trajectory in the international mainstream. By the time of the Reform, the state industry was well behind the international technological frontier for nearly two decades.



Throughout the 1970s and early 1980s, Chinese semiconductor production and research organizations began to import foreign equipment to expand and upgrade technology. A major effort was in the early 1980s to import equipment for 33 semiconductor sites (including factories and research institutes) with a total cost of RMB 1.3 billion (~ USD 150 million) funded by the government. Yet, since the funds were spread out and limited for each site, the importing organizations purchased second-hand equipment in piecemeal. Most of these lines were outdated 3-inch lines that foreign manufacturers intended to eliminate. In the end, the Chinese organizations often could not deploy, use and maintain the imported equipment, with only a few sites made use of these production lines (Wang and Wang 2008: 291-293).

In the 1980s, a set of reforms have been rolled out, both to the state-owned enterprise system and the S&T system in general, and to the semiconductor industry in particular. In the enterprise system, reform moved towards decentralization as industry ministries divested from thousands of state-owned firms and transferred ownership to provincial, municipal and local authorities; more autonomy was given to firms; a tax system was introduced to collect revenue allowing firms to retain some portions of incomes; and non-state forms of ownership were tolerated, leading to the emergence of foreign and private enterprises (Lardy 1998; Naughton 1995; Rawski 1994). In the S&T system, in order to create a market for technology, funding for research institutes were greatly reduced, with some non-priority institutes completely defunded and forced to work with market and firms. Individual researchers were also encouraged to move out and start their own business, creating some of Chinese early S&T enterprises (Lu 2000). Yet, as the nature of Chinese reform being gradual, many of the reform measures were implemented slowly, especially in the enterprise system, with the result that the bureaucratic and hierarchical state industry structure persisted until the late 1990s.

In 1982, the State Council created the “Lead Group for Electronics, Computers, and Large-Scale IC” (电子计算机和大规模集成电路领导小组), a first high-level government body for inter-ministry coordination and strategic industry policy making, chaired by Vice-Premier WAN Li. In 1984, the Lead Group was renamed as “State Council Lead Group for the Promotion of Electronics Industry” (国务院电子振兴领导小组), a name closely resembling similar electronics industry promotion acts in Japan and Korea in the 1950s and 1960s<sup>5</sup>. The Lead Group included important members such as Jiang Zemin, then Minister of Electronics Industry and later President. Nevertheless, the Lead Group only lasted until 1988. The Lead Group’s key policy was to consolidate the state industry and build a small number of key enterprises. It was the government’s response to widely perceived failures in the aforementioned mass importation of foreign equipment by 33 semiconductor sites in the early 1980s. The Chinese leaders considered the industry to be “fragmented” (散) with too many small and rival organizations and “chaotic” (乱) with no effective coordination among organizations in technology acquisition and upgrading. The Lead Group’s measure was to force consolidations, planning the state semiconductor industry to concentrate in two large industrial bases of Yangtze River Delta (including Shanghai, Jiangsu and Zhejiang) and Beijing areas, and a small cluster in Xi’an serving aerospace operations. By the mid-1980s, the Ministry of Electronics Industry divested from the majority of the central-government-owned semiconductor organizations.

Five key state-owned semiconductor factories relatively large scale had emerged between 1988 and 1995, including Huajing Electronics (formerly Wuxi 742 Factory in Jiangsu), Huayue Microelectronics in Shaoxing, Zhejiang (with the first 4-inch line of China built in 1988), Shanghai

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<sup>5</sup> Japan’s Electronics Industry Promotion Act of 1957 and Korea’s Electronics Industry Promotion Act of 1969 used the same Chinese characteristics for Industry Promotion (产业振兴), which have a double meaning of promotion and revitalization. The choice of words of the Chinese government in 1984 did not appear to be random.

Belling, Shanghai Philips (with the first 5-inch line built in 1991), and Beijing Shougang-NEC (with the first 6-inch line built in 1995). The five key enterprises received special funding to acquire foreign technologies and build up scales, and three out of the five national key firms (Shanghai Belling, Shanghai Philips, and Shougang NEC) were Sino-foreign joint ventures, involving Belgium's ITT, Netherlands' Philips, and Japan's NEC, respectively. Table 5 has a detailed description of the origin, foreign partners, technology, employment, and markets of the five key enterprises. By today in 2017, all the five enterprises still exist.

To conclude this section, the modern Chinese semiconductor industry originates from a domestic, state-owned sector with low-technology and lack of scales. China's semiconductor technology started early comparing to its Asian neighbors, but it fell behind severely in isolation in the 1960s and 1970s. The "fragmented" and "chaotic" status of semiconductor organizations and their ineffective use of funds for technology acquisitions in the early days of the reform led the government towards an industrial policy of promoting a small number of selected "key" enterprises. In the 1990s, creating national champion firms equipped with advanced technologies became China's primary industry strategy and the driving force for advancing domestic technology, as I will discuss in the next section.

**Table 5 China's Five Key Semiconductor Enterprises (1988 – 1995)**

Enterprise Name	Founded	Prior SOEs	Foreign partners	Locations	Technology in 1995	Products and Markets	Additional Details
Huajing (later became CSMC)	1989	#742 Factory (Wuxi) and #24 Institute (Sichuan)		Wuxi, Jiangsu	2, 3, 5 microns 4, 5-inch line	discrete devices, bipolar and CMOS ICs, primarily for TVs and audio equip	Project 908
Huayue	1988	#871 Factory		Shaoxing, Zhejiang	3, 5 microns 3, 4-inch line	Analog devices and bipolar ICs for TVs and phones	A candidate for Project 908
Shanghai Belling	1988	#14 Factory (Shanghai) and Shanghai Electronics and Operation Instruments Holding Company	ITT of Belgium	Shanghai	2.4, 5 microns 4-inch line	ICs fore telephone switch	A spinoff from Shanghai Bell Telephone Equipment Mfg. Co, China's first Sino-foreign microelectronics joint venture
Shanghai Philips (later changed to Advanced Semiconductor Manufacturing Corporation, ASMC)	1988	#5 and #7 and #19 Factories (Shanghai)	Philips of the Netherlands (Also Nortel of Canada from approx. 1995-2000)	Shanghai	3 microns 5-inch line	began as a foundry; Philips transferred older tech and producing for export	
Shougang-NEC	1991	Beijing Shougang (Capital Steel)	NEC of Japan	Beijing	1.2, 1.5 micron 6-inch line	IC for color TVs, air conditioners, VCDs, IC cards, clocks, palm PCs	

*Source: Mays 2013, p.101, Figure 4 with author's additional notes*

#### 4.2.2 *Technology Transfers and Project 908*

In the 1970s and 1980s, with a wave of inventions in the consumer electronics driving a rapid growing market for semiconductors, companies in the developed world were innovating even faster in semiconductor technologies. In creating the personal computer (PC), IBM adopted an open architecture business model to source key semiconductor chips, such as Central Processing Unit (CPU), from merchant foundries instead of in-house production. Such a strategy and a growing PC market followed led to the flourishing of a class of semiconductor companies called integrated device manufacturers (IDM) that design, fabricate, and packaging/assembly/test chips to supply end-product makers. Intel, the leading IDM in supplying CPUs and memories for the PC makers, became the largest and most technologically advanced semiconductor company until today (Baldwin and Clack 2000; Lazonick 2009)<sup>6</sup>. Observing such a trend, in 1989, a group of Chinese leading scientists and engineers proposed to the Central Party Committee of CCP to invest in China's first world-class IDM, targeting 1-micron technology (Mays 2013; Chen 2005)<sup>7</sup>.

The State Council approved the proposal in 1990, setting the Ministry of Electronics Industry to sponsor one significant project (Project 908<sup>8</sup>) that would advance Chinese technology to the world frontier. Project 908 planned an investment of 2 billion RMB to upgrade various parts of the domestic semiconductor supply chain, i.e. design, foundry, packaging and testing, materials,

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<sup>6</sup> IDMs were dominant semiconductor companies since the 1980s. Vertical disintegration of the global semiconductor industry occurred in the mid-1990s, as the Taiwanese pioneered in the pure-play foundry business model. Today, IDMs still occupy important market segments such as CPUs and memory chips for PCs. However, in emerging and fast growing segments including smartphone processors and communication chips, the pure-play foundries are dominant.

<sup>7</sup> The other main motivation for Chinese to develop semiconductor technology is defense related. It is widely believed the Chinese leaders saw during the Gulf War, the West had demonstrated superior military capabilities especially precision guided missiles that essentially reside on modern semiconductor chips. However, since the focus of this dissertation is the civilian and commercial technology development, and the Chinese industry policy since the 1990s is sufficiently separated from military technology, I will not discuss military technology.

<sup>8</sup> The project is named 908 because it was launched in August 1990.

and equipment, but the priority is to build a world-class foundry, a semiconductor factory that fabricate/manufacture integrated circuits. Project 908 is also called China's LSI (Large Scale Integration) project as it specifically targets LSI circuits at sub-micron (1.0um- 0.8um) level. One of the aforementioned five key enterprises, Huajing, was selected to undertake the foundry project, taking the state investment of RMB970 million (including 380 million loan from the China Development Bank), to introduce a 6-inch, 0.8um production line from abroad. The remaining funding of Project 908's 2 billion investment were used to establish nine IC design centers, one test and packing firm, and six fab equipment supply projects.

The predecessor of Huajing is the state-owned #742 Factory located in Wuxi, Jiangsu, an industry city in the Yangtze River Delta about 80 miles west of Shanghai. #742 was the first enterprise to import semiconductor fabrication lines from abroad. In 1980, the Factory imported a used 3-inch line with 5-micron technology from Toshiba and had its engineers trained at Japan. The main product of the line is bipolar IC used in TVs. It was said that factory directors at #742 were good among SOEs at pushing quality and improving semiconductor yields, and with some sense of market, they focused on producing low-end bipolar ICs for black and white TVs and profited well from China's burgeoning markets for electronics. In the late 1980s, the #742 Factory even worked closely with local research institutes to develop some design capabilities, including designing, testing and manufacturing the first LSI circuit of China, a 64k RAM, in 1987. In comparison, most state-owned factories at the time were working in silos rarely connected with research institutes and had little sense of producing for markets. By the beginning of Project 908, Huajing had 5000 employees and a self-built 5-inch foundry line, as the country's largest and most sophisticated semiconductor-electronics factory (Fuller 2005; May 2013).

In August 1990, Huajing was established as a new enterprise by merging #742 Factory and #24 Institute (from Sichuan) to undertake Project 908. Project 908 was intended to complete within the 8<sup>th</sup> five-year plan (1991 – 1995) period, yet it was not until December of 1995 that the construction for Project 908 eventually started. The delays were largely political in nature. It took the bureaucracy two years to approve funding, and another three years to approve introducing technologies from AT&T Lucent. Hu Qili, the Minister of Electronics Industry at the time, later illustrated in his memoir the inefficient coordination among ministries in establishing a feasible project plan: when Huajing wanted to import a lithography machine, it had to submit several proposals to different parts of MEI for approval (Hu 2006). While the Ministry of Electronics Industry was formulating and undertaking industry policy, its actions had to be approved by the State Planning Committee to take action. By the time Huajing received money and started fab construction in 1997, the 6-inch line was already trailing behind the international frontier (Chen 2005: 83-88).

By the mid-1990s, Huajing's financial standing was already deteriorating as rampant smugglings threatened its traditional low-end semiconductors market for consumer electronics, which used to be protected by a tariff. To make it worse, Huajing was apparently unable to utilize the newly imported fab line. The communication ICs targeted in 1990 and transferred from AT&T-Lucent were already outdated, and Huajing could not come up with its own designs. One account of Huajing's inability is its lack of skills. Fuller (2005) observed that Huajing's engineers were merely reverse engineering foreign chips since the 1980s, and never developed real skills to make their own designs. Unlike in the machinery industry where taking apart is a learning process, reverse engineering a chip is essentially photocopying the blue print. Therefore, even when AT&T-Lucent transferred relevant design tools and IP libraries, Huajing's engineers had no designs to fill

the new fab. In the other account, Mays (2013) argues that Huajing's problem was organizational. In establishing Huajing, the Ministry of Electronics Industry forced a merger by moving #24 Institute from the inland Sichuan to the eastern Wuxi to strengthen Huajing's R&D capabilities. The #24 Institute was the most prestigious and advanced semiconductor research institute in China's military-industry complex in the 1970s and 1980s, and had undertaken several state projects in advancing IC technologies. Huajing were never able to fully integrated #24 Institute into its organization. It could not move the R&D close enough to production, nor could it have the Institute generate enough designs for commercial chips. In addition, since the #24 Institute's capabilities were probably more in designs for military use anyway, it required learning to adapt to the civilian market. That learning did not happen or happened too slowly under Huajing.

By 1997, the results from Project 908, China's first attempt to build a world-class semiconductor enterprise were dismal. Fortunately, a series of contacts with the Taiwanese between 1997 and 1999 result in a turn for Huajing. In early 1997, Ministry of Electronics Industry invited a group of Taiwanese semiconductor industrialists to visit the Huajing fab and started the negotiation of introducing Taiwanese management. The result was that a group of Taiwanese managers and engineers found a start-up named CSMC (Central Semiconductor Manufacturing Co.) in Hong Kong, and CSMC would lease the 6-inch fab constructed for Project 908 and its 200 employees from Huajing. The group of Taiwanese was headed by Peter Chen (陈正宇), who received PhD in electronics engineering in the US and started semiconductor companies in Taiwan in the 1980s. In late 1997, the deal was approved by the state council. By 1999, the two sides agreed to establish a joint-venture firm, named Huajing-CSMC, with CSMC holding 51% of shares and Huajing holding 49%.



Under Taiwanese management, Huajing-CSMC had a successful transformation. Within 15 months, the 6-inch fab achieved break even. The success of Huajing-CSMC could be attributed to two factors. On one hand, CSMC introduced the Taiwan-originated “pure-play foundry” business model to Huajing. In its essence, the foundry business model is to operate the factory as a contract manufacturer to fabricate chip designs for other firms, thus Huajing-CSMC would no longer need to rely on the less-developed domestic design sectors. On the other hand, Taiwanese management brought capital, management, and access to foreign clients. Even using the same workforce, equipment and plant as before, Huajing-CSMC achieved better results.

Huajing/Project 908 has never become the leading-edge semiconductor firm envisioned by the Chinese state. Nevertheless, its transformation from a state-owned factory to a joint-venture foundry marked an important turn in industry policy and business organization. By 1999, the 6-inch line utilized by Huajing-CSMC was already trailing-edge technology. Yet, by allowing the Taiwanese management to take over a former national champion, the Chinese state signaled the embrace of a more open economic system even in a sector considered critical to national security as long as the system advances Chinese technology. Huajing-CSMC was not only the first pure-play semiconductor foundry operating in China, but it also demonstrated the possibility of operating a modern semiconductor foundry using Chinese technology and engineering workforce. It ultimately served as a bridge between the domestic state industry in the 1980s and the globally-linked industry with diverse ownership in the 2000s (Mays 2013). Yet, before getting there, between 1995 and 2000, the Chinese government pushed another large-scale state project in semiconductor, Project 909, which I will examine in next section.

To sum up this section, in the beginning of the 1990s, the Chinese government formulated an industry policy to create a National Champion firm to advance towards the technology frontier. In the first large-scale state-sponsored Project 908, a leading state-owned factory, Huajing, was selected as the vehicle for technological upgrading. Yet the project's poor results revealed deep structural problems in China's state industry. First, there was simply no sufficient funding from the state-owned sectors to support an extremely capital-intensive industry like semiconductor. At least by 1996, private capital was restricted and limited foreign capital was allowed through the route of joint venturing with state entities. Second, the slow decision-making process in the Chinese bureaucracy could not meet the demand of fast-paced technological change in semiconductor technology. While the Ministry of Electronics Industry oversees the state industry, especially those "key enterprises", it surprisingly lacks the capacity to execute industry policies in China's system of "fragmented authoritarianism", a term used to describe the power in Chinese government system being shared by entities over vertical and horizontal chains of command (Lieberthal and Lampton 1982). Third, using state-owned factories as the vehicles of industry policy were highly problematic. The Chinese state-owned factories were not long ago "vertical silos" in the command economy that did not connect to the science base or to the markets. Even the best performing state-owned semiconductor factory, Huajing, did not develop sufficient capabilities to compete in this newly created market, nor to absorb advanced technologies. By the mid-1990s, the whole Chinese state-owned industry was already on the brink of bankruptcy in the face of intensified competition following the Reform and Opening-up. In 1995, as the Chinese government set for the 9<sup>th</sup> Five-Year Plan (1996-2000), Project 908 was already in disfavor.

#### 4.2.3 *Joint Ventures and Project 909*

In the mid-1990s, while Project 908 was moving slowly, the Chinese leaders were looking for solutions from the outside world. On one hand, like many government-controlled sectors such as automobiles and telecommunications, establishing joint-ventures with foreign firms was a major industry policy for semiconductor. The last three of the five “key enterprises”, namely Shanghai Belling, Shanghai Philips and Beijing Shougang-NEC, were all Sino-foreign joint ventures. Shanghai Philips and Beijing Shougang-NEC built China’s first 5-inch and 6-inch wafer lines in 1991 and 1995, respectively. Throughout the 1990s, these joint ventures operated the most advanced semiconductor fabs in China. Yet, those joint-venture semiconductor firms tend to be dependent on foreign partners for technology transfers, rarely upgrading after the initial technology targeting agreed during founding. These firms were integrated more into the supply chain of foreign partner firms than integration with the local supply chain, as they received inputs and technology from and sold outputs to their multinational partners (Fuller 2005; Li 2011; Interview 1, 15, 23).

On the other hand, top Chinese officials began to establish frequent contacts with the overseas ethnic Chinese community, which have been active in the semiconductor industry from Silicon Valley to Hsinchu, and were often regarded as an important source of knowledge and experience in developing the semiconductor industry in Taiwan (Saxenian 2005). President Jiang Zemin, who was the Minister of Electronics Industry in the 1980s and a member of the “State Council Lead Group for the Promotion of Electronics Industry”, became China’s President in 1993, and showed great personal interest in sponsoring the semiconductor industry. Jiang openly expressed great admiration of the modern large-scale semiconductor companies in South Korea, and was said to be more receptive to overseas Chinese experts than his peers in the party leadership.

In between 1995 and 1999, overseas Chinese experts were heavily involved in the planning of China's next state project in semiconductors, Project 909, and the formulation of a formal industrial policy document<sup>9</sup>, Document 18 (Chen 2011, p.97-103; Hu 2006). As mentioned earlier, the takeover of Huajing by overseas Chinese management were also occurred during this period. In December 1995, the Chinese government issued its 9<sup>th</sup> Five-Year Plan (1996 – 2000) for the semiconductor industry, in which it targets for the construction of an 8-inch fab with 0.35- to 0.5-micron node process technology. The Plan also called for establishing several commercial semiconductor design houses to utilize the fab. With high-level attention, execution of the plan was swift. In April 1996, the State Council joined with the city of Shanghai to fund Project 909, a new project replacing Project 908 to realize China's high-tech ambition.

Project 909 was the last state project in the semiconductor industry with direct government involvement in investing and managing a semiconductor enterprise. It was also the most expensive project, costing over RMB10 billion, larger than the sum of all prior state investment in the industry and more than Japan or South Korea spent at the similar stage of catch-up (Hu 2006, p. 6). To avoid bureaucratic deadlocks occurring in Project 908, the planning and execution of Project 909 were deliberately carried out outside of the established bureaucracy. The premier earmarked funds from The Premier's Fund, i.e. a special category in central government discretionary spending controlled by the premier, to finance the project. An inter-government committee was set up to speed up decision making with consultation from an expert group of ten semiconductor industry specialists (with five of them were overseas Chinese with foreign nationalities). Within four months, the Ministry of Electronics Industry (MEI) and the city of Shanghai were set out to found

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<sup>9</sup> Up until the issues of Document 18, China's state interventions in the semiconductor industry were mostly carried through one-off state projects using the vehicle of state-owned firms (Wang and Wang 2008). More details about Document 18 is discussed in section 4.2.4.

Huahong Group, a new enterprise to carry out Project 909, with a registered capital of RMB4 billion shared by the central government and Shanghai in a 60:40 split. Hu Qili, the Minister of Electronics Industry and a close ally of President Jiang, became the chairman of the board of the new enterprise.

The center piece of Project 909 was the construction of an 8-inch fabrication line. Three approaches were considered in planning: 1) independently develop the technology and construct the 8-inch fab; 2) invest in a fab and invite ethnic Chinese to operate it; 3) joint-venture with a multinational corporation. According to Hu, the leaders of Project 909 already believed that “We must depend on collaboration, not independent-development” (Hu 2006, p. 37), which excluded the first option. Hu also argued that Project 909 needed not only foreign equipment, but also international talent, management experience, intellectual property, and access to the market, as he said “we must bring in international management and technical partners, as other countries did. Eventually we will lay a foundation for further development” (Hu 2006, p. 38-39). To realize the goal of Project 909 of “breaking up the vicious cycle of technology catch-up... we must have intellectual property...” through acquisitions from abroad (Hu 2006, p. 167-168). In the end, the joint-venture option was selected because it was considered to be least risky, and an established foreign firm was more capable in offering technology, management, and most importantly IPs. Nevertheless, Hu Qili’s Ministry of Electronics Industry engaged in contacts with many overseas Chinese industrialists, including Richard Ru-Gin Chang, who later came to found SMIC, the leading domestic firm since the 2000s.

The biggest hurdle in the joint-venture approach was to find a foreign partner. The difficulties were two-fold. On one hand, unlike many sectors the Chinese government successfully implemented “Trade Market for Technology” policies (cf. Feng 2010 for studies of automobile

and telecommunication equipment sectors where the government controlled the market), the government simply did not have a semiconductor market that they could offer. In 1997, the global semiconductor market was also transitioning from a boom to bust as prices fell under overcapacity. Without a guaranteed market, foreign semiconductor companies were skeptical about the prospect of operating an advanced foundry in China in the 1990s. On the other hand, Project 909 targeted advanced technologies raising concerns on US control of export advanced semiconductor production equipment to China (GAO 2002).

The Chinese government literally created a new market to support Project 909. In 1996, the government launched the “Golden Card Project”, part of a series of e-government projects to roll out identification-related cards embedded with computer chips. The Gold Card Project basically created a government procurement market for ICs to be used in National ID cards, Smart (Prepaid) Cards, and cellphone SIM cards worth millions of dollars per year. The government procured these chips from semiconductor design houses set up in Project 908 and 909, which would source production from the planned 8-inch line. In 1999, Huahong specifically established two design houses, one in Beijing (for SIM card) and one in Shanghai (for National ID card), to capture this procurement market (Hu 2006, p. 123-145). Another goal of the government procurement is to enable the semiconductor companies set up in Project 909 eventually to become commercially viable enterprises (Hu 2006, p. 40).

Lastly, Japan’s NEC, the world’s second largest semiconductor company at the time, agreed to join Project 909 and transferred the 8-inch, 0.5um technology. A US\$1.2 billion joint-venture, Huahong-NEC, was established in 1997 with US\$200 million from NEC, US\$500 million from Huahong Group, and additional US\$500 million from bank loans. But both companies shared the management with each held two seats on the board of directors. NEC transferred the complete

8-inch fab equipment and technology, provided management and worker training, and agreed to manage the fab and purchase 35 percent of its output in the first five years. In exchange, NEC appointed the General Manager, took the full charge in running production, sales, and marketing.

The construction of Huahong-NEC fab started in 1997, and the fab entered pilot production very quickly in the beginning of 1999. The initial products were 64MB DRAM memory chips, exported and branded under NEC. Memory chips accounted for 80 percent of Huahong-NEC's total output. With NEC's orders, management and technology, Huahong-NEC quickly ramped up the 8-inch fab, improving yields from 50% to more than 90% within three months, a quality level generally considered to be cost-effective for international competition. Huahong-NEC claimed to earn a profit of RMB350 million in the first full year of production in 2000<sup>10</sup>, an achievement rare in China's state projects thus that leaders of Project 909 can claim early victory.

Yet Huahong-NEC has been criticized that its claimed early successes were achieved under Japanese management of the fab (Interview 2, 19; Fuller, 2005; Mays, 2013). While the Japanese helped to reach the goal of the 8-inch fab construction, other goals of Project 909 including learning management skills and acquiring IPs, had mixed results. Several reports and surveys in early 2000s point to a lack of learning among Chinese managers and engineers in Huahong-NEC. The Ministry of Science and Technology's project examination of Project 909 criticized that the Chinese personnel at Huahong-NEC were generally excluded from "core operations", albeit they admit the Chinese personnel appointed by the government were often bureaucrats rather than true technologists<sup>11</sup>. Fuller (2005) found that the Japanese strategically limited training of the Chinese

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<sup>10</sup> Many Chinese industry personnel cast doubts on Huahong-NEC's early profitability. They believe Huahong-NEC did not have sustaining profits until 2004 (Mays 2013, p.218). Due to high depreciation costs, it is usually very hard for new fabs to achieve positive profits in first 5 to 7 years of operation.

<sup>11</sup> Ministry of Science and Technology Diaoyan Baogao (Investigation Report) No. 11 in year 2002.

engineering staff, who only developed skills in specific tasks without an understanding of the whole fabrication process. In an astonishing case, Chinese engineers at Huahong-NEC could not confirm to customers whether the fab had the capacity to produce chips with certain specifications without consulting to NEC engineers in Japan (Fuller 2005, p. 261-262). Another piece of evidence of the Chinese dissatisfaction is that, as early as in 2003, the 5-year management contract given to NEC was abruptly terminated and new Chinese management brought in. There is some evidence that the Chinese had pressed NEC to transfer more technologies, though. Huahong had spent some RMB10 million to send engineers to acquire the 0.18-micron technology from IMEC, the European semiconductor research center in Belgium. The technology from IMEC was not in fact deployed, but used as bargaining chips to press NEC to transfer equivalent technologies (Li 2011; Mays 2013, p. 220).

In regards to acquiring IPs, on the bright side, Huahong's design houses did received IP transfers from NEC for the designs of Smart Card ICs; on the less bright side, Smart Card ICs were quickly becoming commodities when the Chinese entered the market, prices falling from a few dollars per chip to a few cents within a decade (Hu 2006).

Huahong-NEC was losing money between 2001 and 2003 from a weak DRAM market. At the same time, NEC's semiconductor business was in decline and it was interested in pulling back production to its own plants in Japan. In 2002, Huahong-NEC shifted production from DRAM to smart card ICs (which is a government procurement market), and transformed its business model from IDM to a pure-play foundry. In 2003, Huahong took over management from NEC, brought in a new management team of overseas Chinese, and invited a new foreign partner US-based Jazz Semiconductor, in the hope that the new management and foreign partner would bring in new skills, knowledge and a customer base for their foundry business.



In 2005, Huahong-NEC was listed among top ten global pure-play semiconductor foundries, although the company had continued to live off government procurement for some time. It was not until 2011 that Huahong-NEC received another government grant, “Project 909 Upgrade”, to invest in a 12-inch line. By then, Huahong-NEC has long lost the status as the pioneer of pushing Chinese technology frontiers to SMIC.

While Huahong-NEC achieved mixed results in pushing Chinese technology, the high-profile Project 909 might have contributed more progress in pressing for valuable institutional and policy changes for the industry. As Wang Yangyuan, a top scientist and government advisor argued, “Huahong-NEC set an enormous example for the whole industry and pushed relevant policies...Huahong-NEC proved that China has the conditions and environment for the semiconductor industry... including the infrastructure, market, talent, and policies” (Wang and Wang 2008, p. 298). One important change is the tax reform. In the mid-1990s, China has had a production value-added-tax (VAT) imposing 17 percent tax on imported semiconductors. As mentioned earlier, such a tax/tariff scheme was useless in protecting state-owned firms, because the tiny, light-weighted semiconductors are easy to smuggle, and smuggling along China’s southern borders were rampant throughout the 1990s<sup>12</sup>. Leaders of Project 909 pressed for various tax breaks for semiconductors, imported equipment and raw materials, which were eventually extended to the whole industry in the next decade. The other change is the opening to foreign capital, especially the introduction of venture capital. In 1999, the Ministry of Science and

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<sup>12</sup> The Chinese government organized several anti-smuggling campaigns in the late 1990s, resulting in high-profile corruption cases involved by senior party and government officials. But it was not until China entered WTO in 2001 that dramatically reduced tariffs so that large-scale smuggling could be eliminated. Note that, to join Information Technology Agreement, a WTO agreement, China eliminated semiconductor tariffs in 2002.

Technology confirmed that semiconductor enterprises can seek venture capital that were previously considered off limits (Mays 2013).

Hu Qili, the architect of Project 909, envisioned the project to be a demonstration of the possibility to operate advanced semiconductor enterprises on Chinese soil, albeit the country's rather weak industry infrastructure and even worse legal and institutional environment. To achieve the goal, he envisioned a backbone manufacturing enterprise to support a broader industry chain (Hu 2006). Huahong made important steps towards fostering the industry eco-system, even though the progress might be limited. Huahong was involved in funding several Silicon Valley-based fabless semiconductor companies which later moved to Shanghai. Newave Semiconductor, which received one third of its capital from Huahong's investment arm, Huahong International, was China's first fabless firm financed by venture capital. Newave was founded by a group of overseas Chinese. The company designed radio frequency (RF) chips for telecommunication equipment. The firm mainly operated in Shanghai where it could draw upon the large pool of local engineers but kept the headquarters in Silicon Valley. Newave was highly successful and later acquired by IDT in 2001 for US\$80 million, a record not seen in China at the time. Huahong International subsequently invested in several local startups, including Spreadtrum Communications, which grew to be a top design house for smartphone processors (Hu 2006). While Huahong's investment was largely symbolic, it is hard to overestimate the state sponsorship behind Huajing in encouraging the inflows of capital, talent and startups to China in the next decade.

#### 4.2.4 *Global Enterprise and SMIC*

In July 2000, a few months before China's entry to the World Trade Organization (WTO), State Council issued the "Several Policies to Encourage Software and Integrated Circuits Industry Development" (鼓励软件产业和集成电路产业发展的若干政策), also known as State Council Document 18 of Year 2000 (hereafter, Document 18)<sup>13</sup>. Document 18 is China's first top-down, industry-wide government policy in a legal form towards a specific industry. Regarding the significance of Document 18, a 2003 study by the US Semiconductor Industry Association noted: "With the exception of the auto industry – another Chinese government priority – no comparable sector specific measure has been issued by the government, a fact duly noted by national, regional, and local government officials."<sup>14</sup> It is also a major step away from the Project 908/909-style one-off interventions with direct government involvement in the funding, goal-setting, and operation of specific industrial enterprises. Since the release of Document 18, the Chinese policy moved towards incentive-based policies and regulations for the broad industry that is more in line with advanced industrial economies. Though Document 18 and similar measures would not completely exclude bureaucratic meddling, it should be noted that the audiences of Document 18 are all levels of the government (national, provincial, and municipal), not a handful of elite bureaucrats carrying out a state mission. Such differences can hardly be overestimated.

The background of Document 18 is the anticipation of China's entry to WTO in 2001 and related restrictions on state projects. Similar to other government initiatives in semiconductors in the late 1990s (i.e. Project 909, CSMC-Huajing joint venture), the formation of Document 18

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<sup>13</sup> Full text of Document 18 is available on the website of Ministry of Industry and Information Technology, <http://www.miit.gov.cn/n1146295/n1146592/n3917132/n4062056/n4062057/n4062058/c4142589/content.html> (in Chinese)

<sup>14</sup> U.S. Semiconductor Industry Association, prepared by Dewey Ballantine LLP, by T. Howell, B. Bartlett, W. Noellert, and R. Howe, "China's Emerging Semiconductor Industry," 2003, page 45.

involved heavily with consultations from overseas Chinese, scientists, and foreign advisors. Special treatments and experimental policies tested in Project 909 formed the basics of Document 18. Those guiding principles included: 1) the policy should emphasize industry development, not scientific research; 2) encourage private enterprises (*minying* firms); 3) focus on IC design (software) and IC manufacturing, and encourage foreign capital in all segments of the IC industry, including design, fabrication, and packaging and testing (Chen 2011: 81-82).

While Document 18 is better known outside of China for its controversial Value Added Tax (VAT) rebate that favors local production<sup>15</sup>, the real significance of Document 18 is not in tax breaks but in clarifying the rules for semiconductor enterprises in China. In the early 2000s, various types of high-tech parks set up by Chinese cities were already giving out all sorts of tax breaks, and research has showed that the VAT rebate policy in Document 18 was not effectively implemented due to cumbersome application process: very few semiconductor firms received the rebates and the subsidies involved were small (Fuller 2016). Thus, the real importance of Document 18 was to ease formation of private and foreign-invested enterprises in an industry previously considered sensitive to security and non-government entry was considered “off-limits”. In Document 18, Chinese policy makers wrote that any semiconductor firms operating *in* China enjoy the benefits specified. It encouraged foreign investment in all major semiconductor segments, i.e. design, fabrication, and packaging/assembly/testing; it opened channels for accessing to domestic and foreign capital sources; it required the government to invest in research and the

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<sup>15</sup> The VAT rebate policy gives local semiconductor producers a steep 14% tax rebate out of China’s 17% VAT. In other words, local producers pay an effective 3% VAT. In March 2004, the US government appealed to the WTO for China’s violation of trade rules by using tax to discriminate against overseas producers. Thus, China withdrew the VAT rebate policy in April 2005.

training; and it even made a promise for intellectual property protections (though with little concrete measures).

The release of Document 18 set in motion a powerful wave of innovation and entrepreneurship in the Chinese semiconductor industry. In the early 2000s, entries into the Chinese semiconductor sector included hundreds of fabless design houses and a handful of domestic and foreign foundries that firmly embraced the vertically disintegrated industry structure, in which individual firms specialize in one of the three main steps in the semiconductor value chain:

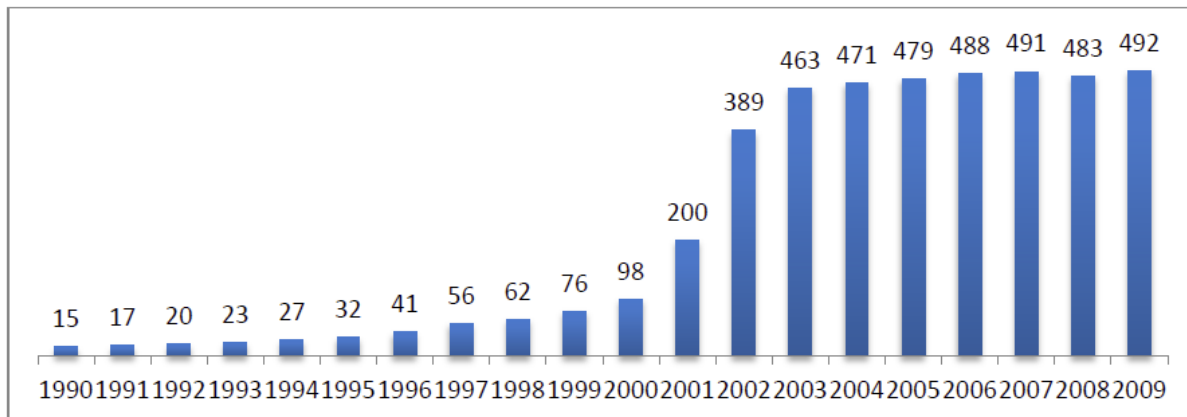
**Design → Fabrication → Packaging/Assembly/Testing<sup>16</sup>**

In the fabless (IC design) sector, the number of new entries soared in the first five years of the 2000s. Throughout the 1990s, the entry of IC design firms never exceeded 20 annually. From 2000 to 2004, the number of design firms increased less than 100 to nearly 500 (Figure 6). A majority of firms in China's new IC design sector are fabless startups that outsourced chip manufacturing to local and international foundries. In the chip manufacturing sector, an influx of talent, technology and foreign capital were supplemented by aggressive subsidies from regional governments to create a new National Champion foundry, Semiconductor Manufacturing International Corporation (Zhongxin Guoji, 中芯国际) or SMIC, in Shanghai. Since 2004, SMIC has been China's largest and most technologically advanced semiconductor foundry, ranking among top five foundries globally. SMIC's business model is a pure-play foundry, fabricating

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<sup>16</sup> Packaging/Assembly/Testing or PAT activities is a low-tech segment in the high-tech semiconductor value chain. Multinational semiconductor companies had offshored PAT activities to Asia early as the 1960s to take advantage of cheap local labor. The backend PAT activities in general do not lead to significant technological learning and upgrading in local industry. Since the development of PAT activities in China is not significantly linked to technological development of the semiconductor industry, I will not investigate in this segment in details.

chips for domestic and foreign design houses (both fabless firms and IDMs). Unlike any Chinese National Champion firms before, SMIC, however is also a private firm with links to the global industry at least as strong as to the Chinese state.



**Figure 6 Numbers of Semiconductor Design Firms in China (1990 - 2010)**

*Source: PWC 2010, Figure 15*

The origin of SMIC is linked to the strong influence of overseas Chinese on the domestic industry in the late 1990s. The founder of SMIC, Richard Ru-Gin Chang was one of several industrialists consulted by the Chinese government. He was said to have been involved in the takeover of Huajing by CSMC, and a strong candidate to run the 8-inch fabs for Project 909. Chang was born in Mainland, raised in Taiwan, and built a career through constructing new fabs for Texas Instruments. In 1997, he founded a foundry startup, World Semiconductor Manufacturing Corporation (WSMC), in Taiwan to compete with the industry leader Taiwan Semiconductor Manufacturing Corporation (TSMC). In 1999, WSMC shareholders sold the firm to TSMC against Chang's will. At the same time, a series of contacts with the high-level Chinese government officials convinced Chang that, with the support from the Chinese government, he could realize his ambition to launch a world-class foundry from the Mainland (Interview 20).

In August 2000, SMIC was established in Zhangjiang science park of Shanghai, the same industrial park where Huahong-NEC is located. Chang assembled a team of over 100 managers and engineers, mainly overseas Chinese (Chinese expatriates in the US, Taiwan and Singapore) but also quite international as a few Americans, Europeans and Japanese were included. Chang recruited them from foundries and IDMs in the US, Taiwan, and Singapore. To fund this US\$1.48 billion venture, SMIC raised capital from international investors, including venture capital firms Walden International, Vertex Venture Holdings (both from Silicon Valley), H&Q Asia Pacific (Taiwan) and Goldman Sachs, as well as various Chinese state-owned groups and investment arms of Shanghai municipal government (SMIC 2004). SMIC's initial technology targeting was a modest 8-inch, 0.18-micron process node, but the firm had aggressive scheduling. By January 2002, its Shanghai fab was already entering mass production.

SMIC is a new type of firm that scholars find it difficult to classify. Since SMIC is registered in Cayman Islands, it is a Wholly Foreign Owned Enterprise (WFOE) by Chinese law. Thus, some scholars classify it as a foreign-owned firm (Breznitz and Murphree 2011; Mays 2013). The problem of such classification is that while having foreign capital and overseas Chinese management, SMIC never behaved like a foreign firm. SMIC operates mainly in China with a few overseas offices and acquired assets. While there is a significant number of Taiwanese in management, SMIC never had any parent organizations in Taiwan or any other foreign countries. The company has significant investment from the Chinese government and the investment grew over time. The obvious contradiction between SMIC's legal class (i.e. WFOE) and its behavior of a domestic firm lead to bizarre recognitions of SMIC. Mays (2013) considers SMIC to be a WFOE National Champion, describing it as an adopted son of the Chinese government. Fuller (2006, 2016) argues that SMIC is more like Foxconn, a unique class of foreign-invested firms managed by ethnic

Chinese with a China-based operation strategy (except that SMIC is not linked to a Taiwanese parent company). The underlying issue is whether SMIC's advanced technology would be considered as Chinese or foreign. While scholars denied SMIC of being Chinese for various reasons, recent reports from renowned news outlets as well as foreign governments generally regard SMIC as a Chinese domestic firm (See PCAST, 2017). In this study, I follow current consensus and SMIC's behavioral traits to regard it as a domestic firm, albeit a new type of domestic firm with global origins and links.

Unlike Huajing or Huahong-NEC, SMIC was not a designated National Champion upon founding, and it has never become a member of the largest state-owned groups controlled by The State-owned Assets Supervision and Administration Commission of the State Council (SASAC). SMIC only became a de facto one after it won out in the domestic competition. In 2000, Huahong-NEC was still the formal National Champion. But SMIC's strongest competitor was another foundry startup, Grace Semiconductor Manufacturing Co., founded in the same year in the same industrial park as SMIC. Grace has deep connections to the Chinese government and Taiwanese business groups, because it has two unusual co-founders: Winston Wang, son of Wang Yung-Ching the owner of Taiwan's industrial conglomerate Formosa Plastics Group, and Jiang Mianheng, son of then Chinese president Jiang Zemin. Perhaps because of these ties, Chinese state banks extended more loans to Grace (US\$800 million) than to SMIC (US\$430 million) in 2001, thus Grace had a slight larger starting capital of US\$1.63 billion comparing to that of SMIC for US\$1.48 billion (Fuller 2005; SMIC 2004). While the internationalized team at SMIC recruited talent globally, Grace had drawn from the pool of skilled semiconductor engineers at Taiwan.

Despite the differences in origins, SMIC and Grace competed on similar operation strategies. Both companies targeted 8-inch, 0.18-micron process technology at launch, a modest



technology level about two generations behind the frontier (though more advanced than other Chinese domestic firms). But their fabs (factories) were of enormous sizes with a volume of 100,000 wafers per month to achieve sufficient scale economies for international competition. Both companies adopted the Taiwan-originated pure-play foundry business model, specializing in the step of production in fabricating semiconductors for independent design houses and IDMs. In the early 2000s, both SMIC and Grace were heavily invested in outsourced production from IDMs, a sort of export processing with advanced manufacturing, in which the Chinese foundries import equipment and materials, use designs from foreign IDMs, and export the fabricated chips. Outsourcing orders filled the fabs quickly, but more importantly, they help to secure relevant intellectual properties (IP) from the outsourcing firms. SMIC received IPs from clients such as Toshiba, TI, Infineon and Elpida, while Grace received from SST, Oki, Sanyo and Toshiba (Interview 1, 15, 20; Li 2011, p.49).

Eventually the race between SMIC and Grace for national championship was determined by business success rather than political ties. An early success in the race is that SMIC ramped up production of its initial fabs much faster than Grace. Commencing construction in August 2000, SMIC's first 8-inch fabs in Shanghai entered mass production in less than one and a half years, including less than one year for qualifying the 0.18-micron process. In contrast, Grace spent approximately 21 – 24 months to qualify the 0.18-micron process (Clendenin 2004). Arguably, SMIC has a more experienced team of production and process engineers. Grace's connection to the Taiwanese skill base was mainly through Nanya, a second-tier memory chipmaker under the Formosa Plastics Group, while SMIC's founding team comes from top IDMs and foundries all over the world, including Intel, Charmed, and TSMC, just to name a few. As revealed later in the TSMC-SMIC lawsuit, engineers recruited by SMIC brought with them important tacit knowledge

and trade secrets, including such knowledge as “detailed process flows... including process target and equipment type” from rival foundries (TSMC court statement, cited in Clendenin 2004).

SMIC’s advantage from early success in quick ramp-up accumulated not only in business (in generating revenue) but also in securing further support from the Chinese government. By the time when Grace entered production in 2003, SMIC already had its Shanghai fabs fully operational and was looking for ways to add additional capacity. In 2002, SMIC acquired Motorola’s 8-inch fabs in Tianjin, and with the support from Beijing’s municipal government, it began to construct China’s first 12-inch fab in Beijing. In July 2003, the China Security Regulatory Commission relaxed the requirements of three-year profitability for Chinese large business (defined as more than US\$2 billion market value) to be listed in Hong Kong Stock Exchange, a move seen as favoring semiconductor foundries (Interview 2, 19). In March 2004, SMIC went public in Hong Kong and New York Stock Exchange, raising additional capital of US\$1.1 billion. With its enormous scale accounting for more than half of the foundry capacity in China in 2004 and support from various levels of the government, SMIC clearly became the new National Champion (ITRI 2011).

The formation of SMIC, a new type of Chinese firm with global origins and links, after the market liberalization of the semiconductor industry in 2000, contributed to an accelerated rate of technological upgrading in the 2000s. That progress can be roughly summarized by three metrics: an increasing share of global production, closing the gap with technological frontier, and expanded capabilities in designing and manufacturing sophisticated semiconductors.

In terms of shares of global production, China emerged as an important producer. In 2000, the Chinese semiconductor industry had a revenue of US\$2.88 billion, accounting for less than 2% of the global industry capacity. China was at best a minor player in this industry at that time. A

decade later, with the investment from the domestic private industry, multinational firms, and the Chinese government, the industry grew to annual revenue of US\$38 billion, accounting for 10.5% of world production capacity. Because the Chinese industry emerged at a time of global industry vertical disintegration, Chinese firms adopted the Taiwan-originated dedicated foundry model, leading to an oversized presence in foundry sector. In the mid-2000s, China already became the second largest foundry capacity provider, following only Taiwan (PWC 2011). In 2016, among the world's largest pure-play foundries, SMIC achieved top five, Huali Semiconductor (merged from Grace and Huahong-NEC) were among top 10 (Table 6).

**Table 6 Top 10 Pure-Play Foundry Companies in 2016**

Rank	Company	Headquarters	Sales (\$M)	Share of Total
1	TSMC	Taiwan	29,488	59%
2	GlobalFoundries	U.S.	5,545	11%
3	UMC Group	Taiwan	4,582	9%
4	SMIC	China	2,921	6%
5	Powerchip	Taiwan	1,275	3%
6	TowerJazz	Israel	1,249	2%
7	Vanguard	Taiwan	800	2%
8	Huali	China	712	1%
9	Dongbu HiTek	South Korea	672	1%
10	X-Fab	Europe	510	1%
	Others		2,251	5%
	Total		50,005	100%

*Source: IC insights, 2016*

In terms of technological sophistication, SMIC as a leading Chinese firm in the 2000s was much closer to the technological frontier than any other Chinese firms in history. In the mid-1990s, after several rounds of technology imports and transfers, the Chinese technology was a decade behind mainstream. State Project 908/909 intended to push closer to the technology frontiers, but both projects encountered major difficulties in chasing a moving target. With the emergence of

globally linked firms, the gap was finally reduced to one generation or one and about a half year (Li 2011; GAO 2002).

In terms of production capabilities, the Chinese semiconductor firms moved a long way from limited capabilities in simple discrete semiconductors to making truly modern computer chips for industrial and consumer uses. In the mid-1990s, the leading domestic firm Huajing mainly designed and manufactured discrete devices, such transistors and diodes. Recall from the previous sections that China had to arrange a technology transfer from NEC to acquire the techniques to design and manufacture cellphone SIM card chips, a very basic technology in modern electronics. Through Huahong-NEC, the Chinese began to be able to mass produce the commodity DRAM at an acceptable quality level. By the mid-2000s, foundries such as SMIC offer a wide range of capabilities to mass produce varieties of telecommunication, multimedia and computer chips for foreign and domestic clients. While the manufacture of commodity DRAM is basically fabricating relatively simple designs repeatedly, those application-specific chips have unique designs customized for each application, often requiring foundries to work closely with designers to implement the design. In addition, those chip designs are increasingly coming from Chinese design houses (SMIC Annual Report 2015).

#### *4.2.5 Rise of Domestic Market and Sustainable Innovation*

The stellar rise of SMIC did not come without substantial risks. For one, the rapid expansion of SMIC relied on government subsidies, especially those from regional and local governments. In the mid-2000s, while already operating in Shanghai, Beijing, and Tianjin, SMIC was asked by local governments in Shenzhen, Wuhan, and Chengdu to build and manage

semiconductor factories in their jurisdictions. As documented in a Harvard Business School case study, “Chang was very committed to a strategy that leveraged the desire of cities within China, as supported by central government policies, to build clusters of high tech companies. By partnering with those cities to build new semiconductor fabrication facilities that SMIC would then operate under contract, SMIC could build scale without necessarily confronting immediate large capital outlays” (Shih 2009, p. 2). SMIC regards such partnerships as a “Reverse BOT” model, where BOT stands for “Build, Operate, Transfer”, a type of public-private partnership in infrastructure provision. In a typical BOT partnership, a private firm would build and operate an infrastructure project, such as a highway, and later transfer the infrastructure to a municipality. In the Reverse BOT model, the Chinese cities would provide the money for SMIC to build semiconductor fabs, have SMIC to manage the fabs under contracts, and later sold the fabs to SMIC (after several years of depreciations thus much lower costs than initial construction). The benefits for SMIC in such partnerships, as explained by Chang, are that “Initially the depreciation [of fabs] is so high, the record for the large foundries so far has been that it is almost impossible to be profitable during the first seven years. So if we do a reverse B.O.T., it makes more sense” (Shih 2009, p. 7). Put another way, SMIC was using public money to build semiconductor factories and had the cities to bear the high initial depreciation costs. Even so, SMIC risked stretching its resources too thin across several geographically distanced locations. By 2011, SMIC pulled back from partnerships with Chengdu and Wuhan, only remaining committed to the Shenzhen fabs, partly because Shenzhen has fabless design firms that can use SMIC’s capacity comparing to Chengdu and Wuhan (Interview 20).

Second, SMIC faced competition from abroad, where rival foundries were not afraid of bringing legal challenges to undermine the new competitor. At home, SMIC benefited from US

export restriction of advanced semiconductor equipment and devices and a Taiwanese government against investing advanced semiconductor facilities in the Mainland (Li 2011). These measures deterred potential entries and helped SMIC to secure the domestic market. But abroad, SMIC is challenged. Recall that SMIC acquired a substantial amount of tacit knowledge through recruiting engineers from rivalry foundries. From TSMC alone, SMIC recruited 100 production engineers (Clendenin 2004). To be fair, such practices of poaching key employees from more advanced competitors was common in the early days of establishing semiconductor industries in Korea and Taiwan, and to some extent it is still used in the industry today<sup>17</sup>. However, SMIC's business model is closely connected to the global industry for both markets and inputs, thus it is potentially more vulnerable to legal challenges in its export markets. From 2003 to 2009, TSMC brought a series of lawsuits in the U.S. courts, suing SMIC for patent infringement and trade secret misappropriation. Those lawsuits ultimately cost SMIC over US\$450 million in financial and equity settlements and resulted in TSMC becoming one major shareholder of SMIC (SMIC Annual Report 2010).

Third, even though SMIC advanced Chinese technology closer to the technology frontier than any other firms, SMIC relied heavily on technology transfer and licensing from abroad for advancing to each newer generation of process technology throughout the 2000s (Interview 14). SMIC's licensing partners in each generation of process nodes include Toshiba of Japan (for 0.13-micron Logic), Fujitsu of Japan (for 0.22 - 0.11-micron DRAM), Elpida of Japan (for 90nm and 100nm DRAM), Infineon of Germany (80 and 90nm DRAM), Chartered of Singapore (for 0.10-micron Logic), and IBM (for 45nm CMOS logic). These licensing agreements on one hand kept SMIC close with the technology trends at relatively low risk. Such is the operation model which

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<sup>17</sup> For example, as recently as in 2015, Samsung was found guilty in court for stealing trade secrets through hiring key engineers from TSMC in developing advanced 14nm node technology.

Breznitz and Murphree (2011) describe as the “Run of the Red Queen” model: Chinese companies are fast followers profiting from proven technologies and business models without taking the risks of pushing technological frontiers. But on the other hand, these licensing agreements depend on specific conditions in the global industry. The European and Japanese semiconductor companies, including Infineon, Fujitsu and Elpida (merged from NEC’s and Hitachi’s DRAM operations), licensed DRAM design and process technologies and outsourced DRAM productions to SMIC. In these arrangements, technology licensing is part of production outsourcing arrangements to extend IPR protections to the contract manufacturers. Yet, those semiconductor companies pursuing outsourcing often had competitive disadvantages. By the early 2010s, Infineon, Fujitsu and Elpida had all eventually exited the DRAM industry. By 2007, SMIC was already exiting the outsourcing business for DRAM manufacturers, quoting “declining DRAM prices” (SMIC Annual Report 2008). But as SMIC shifted gears to produce logic chips for design houses as a foundry, it was also increasingly difficult for SMIC to acquire IPs from rival IDMs and foundries. In 2007, SMIC licensed the 65nm logic process from IBM, but because of restrictions in IBM’s IP portfolio, SMIC cannot modify the process without losing protections from IBM’s IPs. Yet, as a foundry service provider, SMIC competes in providing variations and customizations in the process technology. In developing the next generation 40nm logic process, SMIC then had to perform more in-house R&D and developed an IP portfolio. SMIC’s 40nm did not enter mass production until 2013. In the early 2010s, the apparent gap between SMIC and cutting-edge technology leaders widened again (Interview 14, 20).

In 2009, SMIC co-founder and CEO Richard Chang was forced to resign because of years of lack of profitability and losses in lawsuits with TSMC. Before Chang left, the state-owned Datang Group, a large customer fabricating the Chinese 4G standard (TD-SCDMA) chips at

SMIC, made several rounds of investment in SMIC. In between 2009 and 2010, a bitter fight for control of SMIC broke out between the Datang-supported returnee Chinese management (i.e., Chinese Mainlanders with overseas experience) and the Taiwanese management brought in with Chang. In the end, a senior government official Jiang Shangzhou<sup>18</sup> (who was also an advocate of Chang's operation of SMIC in China in 2000) stepped out to become SMIC's Chairman of the Board. Jiang reaffirmed the government's support of the Taiwanese and international management. Jiang also brought in China Investment Corporation (CIC), the sovereign wealth fund, to invest US\$250 million in SMIC for 11.6% of shares. CIC urged Datang not to take control over SMIC, but instead, SMIC should be kept as an independent and internationalized company (Interview 20).

Chiu Tzu-Yin, a member of Chang's founding team became SMIC CEO in 2011. Dr. Chiu was educated in the US at AT&T Bell Labs, and held key positions in TSMC, SMIC and briefly CEO of Huahong-NEC in the 2000s. Under Chiu's watch, SMIC pulled back from partnerships with Chengdu and Wuhan, focused on varieties in foundry service offerings and needs for local design houses instead of targeting the cutting edge, and emphasized profitability. After exiting DRAM, SMIC's business has been heavily concentrated in two areas: communication ICs (e.g. mobile and computer networks) and consumer electronics (e.g. multimedia paper, digital TV, personal digital assistant (PDA)). These areas are where North American and Chinese fabless design houses excel. Since 2012, SMIC operates with sustaining profits (SMIC Annual Reports, various years).

SMIC's new growth driver is a booming domestic semiconductor design sector driven by local demands for high-quality, low-cost electronics. SMIC had a strategy to support the domestic fabless companies from early on, which only has paid off very recently. In 2005, SMIC fabricated

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<sup>18</sup> Jiang Shangzhou is a senior government official and a returnee in the 1980s. He is widely recognized as a major advocate of China's semiconductor industry and civilian jet aircraft industry.



China's first 3G baseband chip based on 0.13-micron process for the indigenous TD-SCDMA standard, but then domestic clients accounted only for 8% of SMIC's revenue. Per SMIC annual reports, the share of revenue from domestic clients reached 20% in 2009, and increased to 40% in 2013. By 2015, domestic semiconductor design companies surpassed North American firms to become both SMIC's largest source of income and the largest group of users for advanced nodes (defined as 90nm process or below by SMIC). Domestic clients made up almost half of SMIC's revenue and more than half of advanced-node chip outputs. Still, in 2016, the most sophisticated chips SMIC fabricated are the 28-nm Snapdragon mobile phone processor chipsets for the US fabless company Qualcomm.

**The Chinese semiconductor design sector emerged only since 2000. According to estimates by PriceWaterhouseCoopers, the Chinese IC design sector grew from 2.5% of the world fabless industry in 2003 to an oversized 25% in 2015 (PriceWaterhouseCoopers 2016). Unlike the capital-intensive, highly-concentrated foundry sector, the Chinese IC design sector is extremely fragmented, consisting 500 – 700 firms in 2016 and most of them are small-scale operations designing low- to mid-end chips using mature technologies. However, there are a few exceptions. The largest two Chinese fabless companies, HiSilicon and Spreadtrum Communications, are both among top ten semiconductor design houses globally in 2015 (**

Table 7). Spreadtrum Communications, ranked the 10<sup>th</sup>, was founded in 2001 in Shanghai to design mobile chipsets to feature phone/smartphone makers. It adopted a tested business model from Taiwan's MediaTek to provide "turn-key" solutions to Chinese mobile phone makers, especially small- and medium-sized manufacturers with little technical capabilities. In the mobile phone industry, a turn-key solution provides manufacturers with the semiconductor chipsets as well as relevant software and know-how to assemble a phone. Spreadtrum targets the low- and mid-end markets using mature chip fabrication processes, thus it can undercut its main competitor MediaTek in prices. Although Spreadtrum has yet to become a cutting-edge technology leader, it has grown very large in size. In 2015, Spreadtrum had a revenue of US\$1.88 billion (Table 7).

**Table 7 Top 10 Fabless Semiconductor Companies in 2015**

Rank	Company	Headquarters	2014 Sales (\$M)	2015 Sales (\$M)
1	Qualcomm	U.S.	20,066	16,032
2	Broadcom	Singapore	14,072	15,382
3	MediaTek	Taiwan	7,032	6,504
4	NVidia	U.S.	4,382	4,628
5	AMD	U.S.	5,506	3,988
6	HiSilicon/Huawei	China	3,220	3,830
7	Apple/TSMC	U.S.	1,460	3,085
8	Marvell	U.S.	3,733	2,875
9	Xilinx	U.S.	2,429	2,175
10	Spreadtrum	China	1,340	1,880
<b>Top 10 Total</b>			<b>63,240</b>	<b>60,379</b>

*Source: IC insights, 2016*

HiSilicon, ranked the 6<sup>th</sup> globally and China's largest, is a subsidiary of Huawei, the leading telecommunication equipment maker. HiSilicon originated from Huawei's IC design department, and it still mainly supplies Huawei with mobile chipsets, telecommunication ICs, and multimedia ICs. In 2015, HiSilicon has a revenue of US\$3.8 billion, about one fourth of Qualcomm, the world's largest fabless firm. HiSilicon is the only Chinese semiconductor design company that has reached the technology frontier, i.e. designing chips using the latest process nodes and competing with industry leaders on capabilities and features. HiSilicon/Huawei succeeded in advancing technology and innovation through a combined strategy of discovering local demands, aggressively investing in internal R&D, and retention of highly skilled employees, which will be discussed in detail in Chapter 5 on the case study of Huawei. It should be noted that, HiSilicon manufactures its most advanced chips at TSMC, the global leader in foundry. Both HiSilicon and Spreadtrum use SMIC intensively in relatively advanced but not cutting-edge nodes such as 40nm as in 2016 (Interview 33).

#### *4.2.6 New Policy and Industry Outlook*

Since 2012, under President Xi Jing's government with a nationalist economic agenda, the semiconductor industry returned as a high-priority item in the Chinese industry policy at the national level. In June 2014, a new policy "National Framework for Development of the IC Industry"<sup>19</sup> established the "National IC Industry Lead Group" headed by President Xi himself. Xi's policy focuses on increasing domestic production of semiconductors, as China spent more on importing semiconductors than crude oil since 2013 (although at least one half of semiconductors in China are re-exported in assembled products) (Wei 2016).

The 2014 policy framework pledges the governments and private industry to invest US\$150 billion to the semiconductor industry, especially the manufacturing (foundry) segment, in ten years. The new policy uses equity funds administrated by professional financial managers as vehicles to invest in semiconductor enterprises. Since 2014, the Chinese central and provincial governments have established the National IC Fund and various provincial IC funds. The IC fund approach differed on paper from the subsidy-focused national policy in the 2000s, but it is not a long shot from what local governments had been doing to invest in and sponsor semiconductor firms and projects, e.g., the joint ventures between local governments and SMIC in "Reversed BOT" arrangements. The availability of funds in China has stimulated a wave of attempts to merger and acquire Western semiconductor firms, and most of Chinese attempts had failed due to backlashes from European and American regulatory agencies on the ground of security concerns for the extensive involvement of Chinese government funds in these deals (PCAST 2017). Given

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<sup>19</sup> Full texts of the policy can be accessed on the State Council website: [http://www.gov.cn/xinwen/2014-06/24/content\\_2707360.htm](http://www.gov.cn/xinwen/2014-06/24/content_2707360.htm) (in Chinese)

the dubious records of Chinese state-owned entities in buying and utilizing Western technologies, it is not clear whether the current wave of acquisitions will yield better results although the funding is significantly larger. The clear success so far seems to be the acquisitions of Spreadtrum Communications and RDA Microelectronics, two fabless design houses listed on the Nasdaq Stock Market, by the state-owned Tsinghua Unigroup in 2012 and 2013, respectively. Under Tsinghua Unigroup, Spreadtrum and RDA operate as independent companies but they have managed to leverage state resources, attract investments, and grow faster. However, these two companies were Chinese companies operating in China in the first place. Their experience might not be generalized to cases for acquisitions of foreign companies.

Whether Xi's industry policy will achieve its goal or not, the landscape of the Chinese semiconductor industry is vastly different in 2017 from three decades ago when the government started to sponsor the industry. Today, China has a relatively complete supply chain, comprising all key steps of semiconductor manufacturing, including design, fabrication, and packaging/assembly/testing (PAT) of semiconductors, and even some equipment manufacturing. The Chinese design, foundry, and PAT sectors have some of the largest firms in the world, including HiSilicon, SMIC, and ASE Group, respectively. Chinese semiconductor firms have been operating profitably in recent years, while semiconductor firms from traditional industrial centers of North America, Western Europe and Japan are facing deteriorating margins (Interview 23). Even in the advanced backend equipment sector, a Shanghai-based startup Advanced Micro-Fabrication Equipment Inc. (AMEC), has emerged as a second-tier player. AMEC followed the established SMIC receipt combining an international team with generous funding from the Chinese national and local governments (Interview 22).

While injecting capital from the state will stimulate growth, it does not necessarily

guarantee innovation. From the perspective of this study, the most promising sign is that leading Chinese semiconductor companies have accumulated enough capabilities to develop cutting-edge technologies rather than depending on foreign technology transfers. By 2016, SMIC has the capability to manufacture at 28nm node process technology, which is about two generation lagging behind the cutting-edge 14/16nm technology. Even though Intel, Samsung, Hynix and other leading foreign semiconductor firms have extensive operations in China, SMIC's offer is still the most advanced production capability that domestic design houses can access locally. In June 2015, SMIC announced a partnership with Qualcomm and Huawei, two leading foreign and domestic fabless companies, and IMEC, the European semiconductor research institute, to develop an in-house 14/16nm process node technology (SMIC Annual Report 2015). While Qualcomm might use such moves to please the Chinese authority (as Qualcomm was under anti-monopoly investigation by Chinese regulators from 2013 to 2014 for an eventual fine of US\$1 billion), Qualcomm and Huawei are both experienced users of cutting-edge semiconductor technology and process. IMEC, on the other hand, is the world's leading semiconductor research institute, filling the gap of relatively lagged research in semiconductor fabrication by Chinese universities. This research consortium between SMIC, Qualcomm, Huawei, and IMEC might be an emerging solution for Chinese semiconductor companies to innovate at technology frontiers.

### 4.3 The Semiconductor Industry as A Testing Case for Existing Theories

A review of the development trajectory of a Chinese semiconductor industry provides a ground to discuss China's approach to closing and eventually pushing technology frontiers. As I have shown, the semiconductor industry is a critical case because of its high priority on government agenda, enormous economic value, and critical technological capabilities. The importance of the semiconductor industry had compelled leaders in the Chinese government to implement reforms that shaped industry structures and improved approaches to advanced technologies. In Chapter 2, I group innovation theories broadly into three strands: Stage Models, System Models, and Learning Models. Ideas rooted in all three strands have been used to explain the growth of a semiconductor industry in China. Thus, before presenting a theoretical account of innovation pathways in this industry, I use evidence presented here to test existing theories and debunk myths and confusions in the literature.

Stage Models, especially product cycle and value chain theories, have been used to explain the growth of a semiconductor industry in China. A superficial version of the Product Cycle theories, often used by business analysts, describes the industry growth as the global migration of semiconductor industry to China aided by the Chinese government (see PriceWaterhouseCoopers 2002). These analysts see China's entry into semiconductor manufacturing as not fundamentally different from the country's mastering of the production of textile, steels, and toys: the global migration of matured technology and industry into lower-cost locations. Two Chinese-specific factors facilitate such a process: a large Chinese market and a supportive government. The critical issue in this theory is that historically, the timing of semiconductor industry development in China does not fit the narrative. The Chinese government began to sponsor semiconductor projects in the 1980s and 1990s long *before* multinational corporations considered moving semiconductor

manufacturing to China. Several government leaders of the Project 909, including Wang Yangyuan and Hu Qili, repeatedly stated that the purpose of sponsoring a large-scale project is to demonstrate the plausibility of operating a modern semiconductor enterprise on Chinese soil, supported by decent infrastructure, a pool of capable engineers and managers, access to capital, materials, and equipment, and some minimal levels of IP protections. These statements were at least partially validated as major foreign investments did *follow* the government initiatives in terms of timing their investments. Moreover, if combined with a value chain perspective, the product cycle models would expect that China should capture lower value-added activities, i.e. packaging/testing/assembly, first, then move up to higher value-added chip fabrication and design activities. Yet, China moved into chip design, fabrication, and packaging/testing/assembly activities almost simultaneously in the early 2000s with equally strong foreign investment backings in all three segments. In other words, the timing of industry development does not support global industry migration is a direct cause of Chinese development. At most, industry migration is a factor highly distorted by earlier state interventions.

A nuanced view based on the Stage Models is reflected in the “Run of the Red Queen” theory that Chinese companies innovate to follow closely to the technological leaders without pushing the frontier (Breznitz and Murphree 2011). From the product cycle theory perspective, this model essentially pictures Chinese companies positioning themselves to capture profits from given a technology as soon as it is established in the market. According to Breznitz and Murphree (2011), SMIC is described as a successful example of “Run of the Red Queen” model: it adopts the proven Taiwanese business model of pure-play foundry and follows closely with international technology leaders. Breznitz and Murphree (2011) argue that such a model has low risks and high economic returns, thus it is suitable for China, a large developing economy looking for growth-

generating and job-creating opportunities. A closer look at SMIC's short history might reveal that the company in fact adopted two technology strategies at different times. In the 2000s, SMIC was focusing on the exporting market, acquiring technologies through contract manufacturing agreements with foreign semiconductor firms. The contract manufacturing operations, especially those as a second source for foreign DRAM makers, was not guaranteed to be profitable, as the outsourcing firms tended to have sufficient bargaining powers to shift parts of risks to contract manufacturers. In this period, while SMIC's CEO, Richard Chang, had the ambition to pursue advanced technology aggressively, but the mode of technological acquisitions set an upper limit for the level of advanced technology in his pursuit. After SMIC dropped out DRAM manufacturing in 2007, the firm's main strategy was to capture niche markets in mature technology through developing process variations for custom applications. Such strategy works well for SMIC as it captures a growing market of less innovative domestic fabless firms. In the latter period, SMIC emphasized value capture while putting less efforts on closing technological frontiers (Interview 15). SMIC's two business models in both periods fit the description of the "Run of the Red Queen" model, while Breznitz and Murphree most likely observed the firm's behaviors in the earlier period because of the timing of their research. However, the two business models SMIC employed have differences in dynamics in technological learning and thus differ vastly in their implications. In the export-driven model in the earlier period, the dynamics of learning is driven by technology transfers from outsourcing foreign firms. This model is hardly sustainable as either the success of contract manufacturers or the demise of outsourcing firms will undermine the continued flows of technology transfers. In the domestic-driven model in the latter period, the dynamics of upgrading stem from the increasing technological sophistication of domestic foundry users, which presumably would stimulate the development of capabilities in the manufacturers. Furthermore,



the two technology strategies SMIC employed can be seen as two ideal types that exist widely in the Chinese manufacturing base: one type of firms that would eventually compete head-on with foreign firms, while the other type might be more collaborative with more advanced firms. The “Run of the Red Queen” model appears to be unable to distinguish between the two types, as it mainly captures a transitional stage of technological learning. Thus “Run of the Red Queen” model does not have sufficient predictive powers over how the innovation pathway might unfold.

The System Models emphasize roles of different types of actors in enabling technological learning innovation. In the literature of Chinese high-tech industry development, debates are centered around the role of the state (including various levels and functions of the government), domestic firms, and foreign firms. The case of the semiconductor industry provides a window to test theories concerning 1) the relationship between the state and firms; 2) the role and effectiveness of various types of government entities; 3) the roles of domestic and foreign firms, or firms operating under different institutional logics.

In respect to the role of the state, the semiconductor industry case shows that conventional theories of differences between Chinese central and local governments in their roles and performance for supporting high-tech development might be exaggerated. Because the Chinese government is known for “fragmented authority”, theorists have argued that local governments play a critical role in economic development. In “Run of Red Queen”, Breznitz and Murphree (2011) argued that the central government tends to be driven by techno-nationalism ambitions, more likely to undermine the working of markets, and more likely to be involved in bureaucratic meddling of enterprise operations. These behaviors all lead to grand plans that fall short. In contrast, the local governments, under fierce inter-regional competition, tend to be pragmatic in economic policy and planning, adaptive to changes in industry structures, and accommodating to

the needs of enterprises. The result is that the best performing enterprise sectors in China tend to concentrate in areas with strong regional governments and less meddling from the central government. The case of the semiconductor industry shows that such an argument might suffer from a survival bias, i.e. researchers might be biased towards successful cases where selected regions succeed while ignoring failed cases. It is easy to observe in the semiconductor case that the most successful firms are closely tied to local governments while the small number of high-profile central government projects had achieved little. However, the experience of specific enterprises does not suggest Chinese local governments are more capable in sponsoring semiconductor firms. Recall that in the mid-2000s, SMIC expanded with subsidies from local governments through “Reversed BOT” agreements. The packages provided by Chinese cities have converged, with less developed cities tending to be more generous in providing subsidies. But SMIC thrived in Beijing and Shanghai while abandoning operations in Wuhan and Chengdu. Nor did the local governments in general have a higher rate of success than the central government. As I showed in a previous study, in the mid-2000s, there were local investments in 130 semiconductor fabrication sites across 15 provinces, few of them reached market (Li 2016). What is clear is that the most successful semiconductor enterprises thrive in a few high-tech centers, such as Shanghai and Beijing, but such success could be attributed to various regional factors, such as industry clustering, better infrastructure, pools of human resource, agglomeration economies, etc. In contrary to theorists favoring local governments, this case study shows that policy learning by the central government in the period of the late 1990s might be especially important as it laid institutional foundations for later developments. In this period, Chinese leaders learnt that, through executing Project 908/908, handling the aftermaths, and interacting with outside experts: 1) semiconductor enterprises should be operated as commercial entities, not science projects, to be

effective in innovation; 2) experimenting to invite overseas Chinese management for key enterprise; 3) involving foreign and overseas Chinese experts in drafting the new industry policy in form of a legal document (i.e. Document 18) (Chen 2005). Lessons from the state projects and subsequent learning and actions at the central government level shaped how the Chinese semiconductor industry and enterprises would be structured legally and institutionally in the next decade. It is true that local governments in China are especially active in upgrading infrastructure, subsidizing business costs, and from time to time providing necessary protections to compensate for institutional voids, i.e. a lack of property right protections. However, it would seem to be a mistake to underestimate the role of the central government which ultimately lays out development blueprints and controls the directions of reform and local experiments.

Another type of System Models concerns the performance differences by different types of firms. Fuller (2005, 2016) observes that the most innovative firms in semiconductor and other high-tech industries are neither domestic nor foreign firms, but a type of hybrid firm: the firms that are foreign invested but have (overseas) Chinese managers and base entire operations in China. Fuller argues that two factors underpin the success of the hybrid firms. On one hand, the hybrid firms are subjective to financial disciplines imposed by foreign investors, allowing them to outperform state-favored domestic firms that have lost market disciplines from overgenerous state sponsorship. On the other hand, a China-based operation strategy gives hybrid firms more incentives to invest in local capabilities and upgrade Chinese technology than conventional foreign-invested firms that perceive China merely as markets or sources of input. Fuller's study concludes that the success of the Chinese high-tech industry is built on enterprises operating on the principle of foreign institutions, or in another word, development through "importing institutions" (Fuller 2016). In this study, I disagree with the conclusion of the oversized role played

by foreign institutions, while the evidence presented here do confirm some of Fuller's observations, especially that the Chinese managers, engineers and scientist with overseas experience tend to provide the critical inputs of technological, management, and market knowledge to the most innovative Chinese companies. However, to argue that the source of success of the so-called hybrid firms are financial and institutional independence from China could be exaggerated. Here are three counterarguments.

First, the hybrid firms, especially the large ones, have close relationships with the Chinese state. As I have showed, companies like SMIC form relationships with all levels of the Chinese governments, from personal contacts between top government officials and SMIC executives even before founding of the company, to financial stakes from various local governments. Arguing that firms like SMIC are somehow able to operate under non-Chinese financial disciplines while maintaining close financial and non-financial ties with the Chinese state seem to be contradictory. Second, the relative independence of the hybrid firms was deliberately created by policymakers. The case at hand is that in 2009 when the state-owned Datang Group intended to take controlling shares of SMIC, it is the Chinese Sovereign Wealth Funds that step in to invest in SMIC and urge Datang to restrain from undermining SMIC as "an independent international foundry". In this sense, how much independence SMIC and other "hybrid" enterprises alike might enjoy is completely subject to the will of the Chinese state. Finally, most hybrid firms evolve to behave more like conventional domestic firms over time, but that does not undermine their commercial success. The most successful IC design and manufacturing firms have all evolved to become more domestically oriented, as they attain more revenue from local clients. Such adaption is driven by the need to better access local markets and state resource, but it is also because the locus of innovation shifted inwards to domestic markets.

#### **4.4 Innovation Pathways and Technological Learning**

In this section, I present an alternative explanation of how technological capabilities are developed and accumulated in the Chinese semiconductor industry. Central to this explanation is the view of innovation pathways, by which I mean the historical and evolutionary process to develop and accumulate technological and productive capabilities to engage in innovation. Specific to the case is that innovation pathways in the Chinese semiconductor industry shifted over time, as the Chinese attempted different approaches in solving challenges in processing technological uncertainties, financing large-scale investments, and building effective organizations in a globalized industry.

Processing technological uncertainties is the most obvious challenges for any nations to develop a semiconductor industry. Technological innovation in semiconductor devices exhibits two traits: a high rate of innovation and dependence on tacit knowledge. First, unlike mature industries where the rate of innovation is low and technological frontier is stable, the semiconductor technology is characterized as a constant rate of innovation governed by so-called Moore's Law. Leading firms of the industry are pushing technological frontiers constantly in all aspects of design, manufacturing, and packaging. Second, although semiconductors is a science-based industry, substantial knowledge required for innovation is tacit, accumulated through long experience in manufacturing and R&D (Hatch & Mowery 1998). Even though semiconductor technology development might experience so-called architectural innovations (for example, a most recent such shift is from planar CMOS architecture in 28nm lithography to the 3D FinFET in 14/16nm lithography), the long-standing leadership of firms such as Intel, TSMC, and Samsung have not weakened. This proves the critical role of accumulated experience in the innovation process. In short, for new entrant firms in the semiconductor industry, to catch up with the frontier

is to aim for a moving target, requires learning and innovation at even faster pace than the leading firms.

A second challenge in developing the semiconductor industry is to mobilize capital for extremely large investment. A modern semiconductor fabrication facility costs billions of dollars to build. With such high initial fixed costs, a new semiconductor manufacturer might take several years to recover the initial investment and gain profitability. Additional hundreds of millions of dollars for maintenance and more money for investment in R&D have to be spent annually just to keep up with the moving technological frontiers. To simply overcome these financial hurdles in operating a semiconductor enterprise, it requires capital investment in a large sum and in a continuous manner (Baldwin & Clark 2000).

A third challenge is to build effective organizations for learning and innovation, and adopt governance and management practices new to the Chinese environment. The semiconductor industry is a globally organized industry. Being part of the global supply chain imposes global rules on domestic industries. For example, the pure-play foundry model requires the foundry, as a contract manufacturer, to protect client's intellectual property (IP) and implement internationally recognized IP practices. As part of a globalized industry, the Chinese firms need to compete for talent globally. The human resource practices in Chinese firms, as another example, need to change accordingly, that is, changing from the life-long employment system in state-owned enterprises to those of Silicon Valley-style stock based incentives, in order to attract high-skilled managers and engineers who enjoy global mobility. Thus, operating a modern semiconductor enterprise could involve adopting to a complicated set of globally accepted rules and norms, which might or might not be compatible with the domestic institutions. In other words, there are uncertainties in creating organizational forms new to the Chinese environment.

To overcome the technological, financial, and organizational challenges in the semiconductor technology, the Chinese approach evolved over time. There are three types of approaches that emerged, and each approach dominated industrial policies for an extended period of time. These three types of approaches are identified by the organizational form of leading industrial firms, which has evolved from state-owned enterprises, to Sino-foreign joint ventures, and to new domestic firms with globalized origins. Each of the three types of firms represent drastically different ways in processing uncertainties in technology development, financing large investments, and handling relationships with external and internal actors. Accordingly, I divide the history of the Chinese semiconductor industry into three phases (Table 8).

**Table 8 Three phases of the Chinese semiconductor industry**

	<b>Initial Stage (1980 – 1995)</b>	<b>Transition Stage (1995 – 2004)</b>	<b>Take-off Stage (2004 –)</b>
Forms of Industrial Organization	State-owned Enterprises	Sino-foreign Joint Ventures	Globalized Domestic Firms
Operation strategy	From production units to profit-generating firms	From state projects to modern enterprises	From outsourcing manufacturers to serving local industry
Agency/Initiatives	Factory directors, local bureaucrats (Bottom-up)	High-level leaders (Top-down)	Globally recruited managers and engineers (Bottom-up)
Technology source	Indigenous development, piecemeal equipment importation, foreign products on market	Foreign JV partners (multinational corporations)	Clients (incl. outsourcing firms), brain circulations, R&D consortia
Learning strategy	Reverse engineering, indigenous development	Targeted technology transfers from selected partners (equipment, product design, software, personnel training, IP, etc.)	Technology transfer (IPs and licensing), tacit knowledge embedded in human movement, merger & acquisition
R&D organization	Fragmented R&D and production	Focus on implementing tech transfers, emphasize on production	Within firm integration, collaboration with clients and research institutes
Access to Finance	Central government funding	Central government funding, foreign investment	Central and local government funding, foreign direct investment, financial market (foreign and domestic)



The state-owned semiconductor enterprises emerged from the reform in the 1980s formed the initial phase of the industry, in which the SOEs were vehicles to industry development. At the beginning of the reform, policymakers perceived the backwardness of the Chinese industry as merely technical: with upgrades in equipment and tools, those Chinese state-owned organizations would grow into high-tech producers. Nevertheless, the success of the leading firms depended on the transformation of their organization from workshops within a planned system to independent, profit-generating entities that can survive in market competitions. Those succeeded in this task tended to be led by entrepreneurial factory directors supported by local bureaucrats, as shown in the case of Huajing Group. In this phase, the acquisitions of technology gradually shifted from indigenous development towards piecemeal equipment imports and supplier training (due to limited funding) and reverse engineering of foreign products that were increasingly available. These state-owned enterprises had a weak foundation for both indigenous development and reverse engineering, as SOEs inherited from the planned economy a fragmented R&D organization where the labs and research institutes were historically disconnected from factories. The state, mostly the central government, provided funding for investments in advanced technology, but money was limited, slow and spread out for competing needs. While later in this phase the state consolidated funding to a small number of selected National Champions, the pattern of learning and development did not change much. Taken as a whole, the Chinese state and its SOEs demonstrated little capability to handle uncertainties: they abandoned the indigenous, experimental approach to technology development in favoring less risky methods of importing foreign technologies; the central planning system was unfit for meeting the needs of large and long-term investment at enterprise level; the state-owned firms were struggling to adopt for the emerging market economy. This phase ended around 1995 when state decisively turned to a joint-venture approach.

In the 1990s, the Chinese government sponsored national projects targeting advanced semiconductor technologies, which in retrospect, formed a transitional phase. A second approach emerged as Sino-foreign joint ventures became spearheads in advancing domestic industry and technology towards goals in five-year plans. In favoring Sino-foreign joint ventures over traditional state-owned firms, Chinese leaders considered the wholesale purchase of foreign technologies, including equipment, product design, software, personnel training, IPs, and so on, as well as adopting foreign management and organization. As top government officials were -hands-on designing and driving these large-scale developmental projects, local initiatives were less visible. Private semiconductor firms were still out of question. Yet the Sino-foreign joint ventures were asked to transform themselves from state projects to truly modern enterprises with integrated organizations, a task in which they achieved little success. Part of the failure is that their learning strategy overly relied on the multinational corporations recruited as foreign partners, in which the joint-venture firms lost control over their directions in strategy, operation, and technology. Those joint ventures developed manufacturing capabilities under foreign assistance, but the hope to move beyond transferred technology and generate their own technologies were not realized. Nevertheless, through these state project experiments, the Chinese learnt: 1) in terms of financing investments, personal involvement of top leaders created new routes outside of the old planned system of resource allocation for semiconductor enterprises to access domestic and foreign capital. The new sources of funding are larger in size and deployed faster than central planning. 2) In terms of building organizations, the Chinese leaders use the joint venture enterprises as showcases to demonstrate the possibility of operating modern high-tech enterprises in the Chinese institutional environment. The high-level attention created opportunities to initiate important institutional changes, including reforms in industrial policy making, taxation, import-export regulation, and

industrial finance.

In the early 2000s, the industry entered the take-off phase with the establishment of a new type of internationalized Chinese firm, representing a third and newest approach to industry and innovation. Exemplified by SMIC, these firms have deep roots in China with close ties to central and local authorities and draw on local resources of upgraded infrastructure and pools of engineering talents, but they thrive on internationalized teams of managers and technologists and are embedded in the networks of global production. Unlike the foreign-invested multinational subsidiaries or joint ventures, these firms are more motivated to advance local technology and be adaptive to local institutions. As a result, the new domestic firms are more likely to secure long-term successes through turning experience accumulated from exporting into advantages in innovation for local markets. In this phase, the state appears to have settled on these globalized-local firms in their organizational forms to compete internationally and advance technology at home. Entrepreneurs and industrialists with overseas backgrounds are allowed to build their organizations and take control. The autonomy and distance from the state give these firms freedom to pursue strategies for technological learning, including not only formal technology transfers, IP licensing, and merger & acquisitions, but also tapping into perhaps the most important source of tacit knowledge: overseas Chinese and foreign talent. With those human resources, these firms can finally form integrated R&D functions and collaborate with client firms in technological development. In addition to government funding and foreign investment, domestic and foreign financial markets are gradually opened to allow financing of the capital-hungry chip business.

What does this view of innovation pathway reveal about China's innovation capabilities that is the central question of this study? I argue that there are at least three insights:

First, the history of the industry shows that developing a broad set of capabilities for

semiconductor technological development requires extensive resources, and even an entity as powerful as the Chinese state cannot drive the process alone. In each of the three phases of the industry, industry development has been hindered by desynchronizations.

In the initial phase of 1980s and early 1990s, the state industry was disconnected from global production and markets. Huajing, a leading SOE, was more successful than other SOEs because Huajing was sensitive to the local markets, producing low-end transistors to supply the booming consumer goods manufacturers. However, the grasp of local markets was quickly lost as globalization allowed Chinese OEMs to use higher quality and cheaper semiconductors from imports. The government's push of SOEs to upgrade using technologies targeted by policy makers only further detached the SOEs from local markets while it did not promote integration with the global industry either.

The two statist pushes in the 1990s, Project 908 and Project 909, were both unsuccessful in generating anticipated results. Because of severe corporate governance and management issues haunting Chinese SOEs, the state force failed to synchronize with the pace of globalization and local market development. Under globalization, even the government could not create a meaningful market under Chinese control with sufficient size and sophistication to support local firms. The government's decision to leave little strategic autonomy at enterprise level only worsened the subordinate position of Chinese firms in participating in MNC's supply chains.

In the early 2000s, an export-driven business model was established by the new foundry firms supported by subsidies from local governments. Yet, this model suffered from a disconnect from the local market, and the pace of growth proved to be unsustainable and highly subjective to fluctuations in the international market.

Second, the historical view of innovation pathway reveals the origins of the new

semiconductor industry and firms in the 2000s, why they adopt current organizational forms, and how they fit in the Chinese economic and political system. Previous studies have attributed the success of the new industry to an interplay of global supply chain integration and local competition (Breznitz and Murphree 2011) or Chinese firms disciplined by Western financial institutions (Fuller 2006, 2016). However, as I showed earlier, these arguments are flawed. They fail to grasp the institutional foundations of the new domestic enterprises. I argue that the very foundation of these new enterprises is a tacit alliance between the Chinese state and a globalized entrepreneurial class. This alliance was formed through a set of events in the late 1990s, including the inclusion of overseas experts in policy consulting, the takeover of a failed national champion firm (i.e. Huajing) by overseas Chinese managers, and the contacts between Chinese leaders and the overseas community. Some of the events might seem contingent: the takeover of Huajing was under the circumstance that in the late 1990s, the Chinese government was under immense pressure to reform its state-owned enterprise sector, and thus they were more willing to take radical measures. Other might seem inevitable: the continuous fallouts of the state projects had proven that at least alternative organization models should be sought. Through these events, an alliance between the Chinese state and the overseas Chinese entrepreneurial class formed on the ground that the overseas Chinese help the Chinese government to realize its technological ambition while the Chinese state supports those entrepreneurs to build business otherwise impossible.

This pathway view explains features of the new semiconductor firms and industry: the enterprises created by overseas Chinese entrepreneurs including the new national champion firm SMIC are able to operate independently from government control, while the government instituted as set of changes in rules and policies to accommodate them. While receiving generous backing from the state banks and local governments, these new enterprises were free to adopt Western

governance structure, human resource practices, and inter-firm relationships. This view also shows the path dependency of the Chinese approach: while the entrepreneurial system in the semiconductor industry is open to overseas entrepreneurs and foreign investment, it is still closed to domestic private sector, especially in the capital-intensive foundry segment usually requiring extensive state support.

Third, the Chinese appears to have not settled on an institutionalized method to deliver long-term, high-risk capital to innovative industries. There are several rounds of centralization-decentralization in allocating the authority of funding decisions at different level of the state. The decentralization in the 1980s created “chaos” in funding decisions and low efficiency in allocating resources forced the government to decentralize in the 1990s. However, the high risks from centralized decisions and the cost in political energy to push certain projects led to decentralization in 2000s. And again, the issues of low efficiency and lack of relevant knowledge to identify good/bad projects emerged at local level reemerged (Li 2016). In the mid-2010s, the Xi administration is opting for a re-centralization strategy in consolidating financial power within a handful of powerful central government agency. It remains unclear whether such strategy will work. Nevertheless, the cycles of centralization-decentralization show that China still lacks an institutionalized method to deliver long-term, high-risk finance, which is critical in innovation successes in this industry.

## **4.5 Chapter Conclusion**

In this chapter, I present a detailed case study of how semiconductor technological and industry capabilities are created in China at an industry and firm-level analysis. Mastering semiconductor technology is important, because semiconductors empower innovations in a vast

range of ICT industries China both leads and depends on. Through a historical account of three major approaches in industrial policy and organizational reform the Chinese employed, I demonstrate the evolving innovation pathway in overcoming challenges and uncertainties in the innovation and development process. Using this evidence, I clarified myths and confusions in the literature, especially the roles of product cycle, foreign investment, the functions of different parts of the government and their relationships with business, and foreign institutions.

My main argument is that a new type of domestic firm, created by overseas Chinese entrepreneurs with global linkages, drives growth and innovation in the semiconductor industry. The institutional foundation of such firms is a tacit alliance between the Chinese state and overseas Chinese elites formed in the late 1990s in response to the failures of large state projects to build semiconductor enterprises. The new type of semiconductor firms has found a synchronization of state, market, and globalization forces, as these firms are embedded in the global production systems, can exploit expanding local markets, and are backed by the Chinese state in finance and the development of advanced technologies.

A counterargument to this argument is that the Chinese semiconductor industry would have still become globalized and more innovative if the contacts and alliance between the government and overseas elites had not occurred. The experience of the automobile industry, another priority of the Chinese government, might serve as a counterfactual. Similar to the semiconductor industry, the automobile industry adopted the Sino-foreign joint-venture policy in the 1980s and 1990s to build national champions (Feng 2016). The differences are those joint-venture automakers, although un-innovative, were highly profitable, thanks to the government controlled domestic market. By the time the government decided to liberalize entry to the automobile industry and urge the domestic firms to innovate, domestic private firms occupied the space left by the joint ventures.

But the automobile industry as whole has never achieved the level of globalization and innovativeness as the semiconductor industry did.

In this regard, one implication of this finding is that the most critical factor in determining innovativeness of the semiconductor industry might not be capable local governments, open to foreign investment, or adapting Western corporate governance structure. Rather, it might be maintaining the relationship between the Chinese state and the entrepreneurial class, especially the overseas Chinese elites.

There are inherent risks in such alliance. On one hand, the success of overseas-entrepreneur-created enterprises will inevitably nurture more home-grown talent who would be able substitute the role currently played by the overseas entrepreneur class. On the other hand, the growing importance of the domestic market which will reduce the perceived value of the overseas entrepreneurial class and the willingness of the state to cooperate with them.



## **CHAPTER 5. THE TELECOM EQUIPMENT INDUSTRY**

### **5.1 Chapter Introduction**

Huawei Technologies, a telecom technology company, deserves special attention in studying innovation in China. By any measure, Huawei today is China's most innovative company. In 2016, Huawei spent over US\$10 billion on R&D, placing it among the world's top 10 R&D spending companies (PriceWaterhouseCoopers 2017). It holds over 60,000 patents, including 40,000 or more international patents filed outside of China, easily making it the largest patent holder in China. Huawei is a top competitor globally in most of its business lines, from telecommunication infrastructure, to network gear, to smartphone devices. No other Chinese companies are even close to the level of achievements Huawei had managed, even in the telecom equipment industry. Studying Huawei's success trajectory might yield a great deal of insight into not only how Huawei became successful but also the future Chinese firms might or might replicate Huawei's success in other industrial sectors.

. Huawei was founded in 1987 by Ren Zhengfei, a veteran Chinese army engineer, with seven partners in the southern China city of Shenzhen. The company grew rapidly in the following two decades. It gained foothold first in the Chinese rural markets in the 1990s, and then turn quickly towards an aggressive overseas expansion. By the 2000s, it became a leading telecom equipment supplier in China while simultaneously emerging as an important player in wireless telecommunication technologies. By 2014, Huawei officially surpassed Ericson of Sweden with a recorded income of US\$46.5 billion, making it the largest telecom equipment maker in the world by revenue. Yet, even today, Huawei remains a private company, as the company is legally owned

by a collective ownership of its 70,000 Chinese employees through two company unions (Huawei 2016).

While there are numerous studies on Huawei being conducted, there are still plenty of myths and confusion about the company's meteoric rise. Huawei's private ownership is especially unusual to the eyes of outside observers, given the context that the telecom equipment industry is heavily supported by the Chinese government. The state sponsored of a set of industrial promotion campaigns, from the "Trade Market for Technology" in the 1980s and 1990s to the indigenous standard development in the 2000s, with the goal to create state-owned national champion firms to compete globally. Huawei, a private company's success can hardly fit the plan of Chinese policy makers, at least until the late 1990s (Fan 2006). Some speculated from Ren's veteran status to accuse Huawei for having ties with the Chinese People's Liberation Army, which assists Huawei through spying and securing advanced technologies (Gilboy 2002). Not only Huawei has consistently denied such accusation, but it neglected a fact: Great Dragon Telecom, an army research institute spinoff company with real connections to the PLA and one of strongest domestic firm in the 1990s, achieved far less success in technological development than Huawei. Others see Huawei as some form of state-owned enterprise in disguise, being popped up by cheap credit from the Chinese banking system (Fuller 2005). None of the previous studies have addressed the real myths in Huawei: why and how did Huawei maintain a very high level of investment in innovation activities? The company regularly spends over 10% of revenues on R&D, and has roughly 40% of employees involved in R&D activities (Table 9).

**Table 9 Huawei's revenue, employment and R&D (2006 – 2015)**

<b>Year</b>	<b>Revenue (US\$ million)</b>	<b>R&amp;D as % of sales</b>	<b>N. of Employees (thousands)*</b>	<b>R&amp;D employees (thousands)</b>	<b>R&amp;D staff as % of employees</b>
2006	8,504	10%			48%
2007	12,858	10%	81	35	43%
2008	18,354	8.40%	86	37	43%
2009	21,837	8.90%	95	43.6	46%
2010	27,659	9.70%	116	51	46%
2011	32,396	11.60%	140	62	44%
2012	35,353	13.70%	150	70	45%
2013	39,463	12.80%	150	70	45%
2014	46,515	14.20%	169	76	45%
2015	75,103	14.60%	178	80	45%

*Source: Huawei annual reports, various years; author's estimation*

*\*Employee number is estimated from the number of R&D employee and percentage of R&D employees*

In this study, using data from interviews, first-hand observation and archive records, I intend to advance a view that Huawei's success is built on a set of technical innovations, which are grown out of a system of long-term technological accumulation. I argue that these technological innovations are key for Huawei to capture markets, and thus Huawei's growth is sustainable. The basic fact is that in the mid-1990s, Huawei was among a group of Chinese companies, both state-owned and private, in developing and commercializing homegrown digital switch technology. Yet by the early 2000s, Huawei became the most successful one by improving the technology to adapt to local conditions in capturing markets in less developed parts of China. In the mid-2000s, Huawei pioneered the communication-equipment industry in commercializing distributed wireless base station and SingleRAN soft switch technologies, and subsequently became a technology and market leader.

In following parts of this chapter, I first examine Huawei's path of growth and the process of making Huawei's major technological innovations that allowed the company to compete and

thrive, including, but not limited to, C&C08 program-controlled telephone switch, distributed wireless base stations technology, and SingleRAN radio access network switch technology. While the C&C08 switch is a well-known example of Huawei's innovative products, this study is the first systematic documentation of the innovation process of Huawei's wireless technology. Huawei's wireless technology success is the key for the company to break into the rank of global innovation leaders and push technology frontiers.

Next, I link Huawei's technological innovations to its system of long-term technological accumulation. I argue that, to direct and utilize the company's high cost investment in R&D, Huawei has made three-pronged investments in obtaining user knowledge, in accumulating fundamental technologies, and in maintaining a motivated and flexible workforce.

Finally, I discuss the implications of Huawei for understanding Chinese innovation, from various angles of technology, market, and government-business relations. The limitations of the Huawei model are also discussed.

## **5.2 Industry and Policy Background**

### *5.2.1 China's Telecommunication Industry and Market*

The Chinese telecommunication market has grown from barely existing to the world's largest in the last 30 years. In 2012, China had over 1 billion mobile phone users and over 500 million internet subscribers, surpassing the United States to lead the world in mobile phone and internet subscriptions (Reuters 2012). This dramatic improvement in telecommunication infrastructure occurred in a relatively short time and started from an extremely poor base. In 1980, only 0.2 percent of the Chinese population had access to fixed-line telephone connections. The

penetration of telephone services reached a peak of 28 percent in 2006 before people substituted for fixed lines with mobile phone services. The takeoff of mobile phone and broadband internet usage is even more impressive. Throughout the 1990s, less than 1 percent of the Chinese population used mobile phone. By 2014, more than 90 percent of the population had mobile phone subscription. Subscription to broadband internet increased from merely 0.3 percent of the population in 2002 to 20 percent in 2015 (World Bank 2017).

Under the background of explosive growth in domestic demand, the Chinese telecommunication equipment industry grew into global prominence. Nevertheless, the growth of the industry has been through multiple stages. At the beginning of China's economic reform in the 1970s, the telecommunication industry was part of a state monopoly, the Ministry of Posts and Telecommunications (MPT). The MPT was the regulator, service provider, and at the same time, producers of telecommunication equipment. The state industry affiliated with MPT was characterized as small in scale, backward in technology, inefficient in operation, and a lack of investment capital (Wan 2001).

China's industrial policy in the 1980s and 1990s emphasized imports of foreign switch technology and setting up Sino-foreign joint ventures with multinational corporations to promote local production. As populated in several industries, and illustrated earlier in the semiconductor case study (Chapter 4), these Sino-foreign joint ventures were set up on the grounds of "Trade Market for Technology", in which foreign firms were granted access to the government-controlled market on the condition of transferring technologies China desires. In the telecommunication sector, major multinational corporations were involved in this scheme, including Nortel (1984), Nokia (1985), Motorola (1987), Lucent (1988), Cisco (1994), Qualcomm (1999), and Siemens (1999) (Fan and Gao 2016). To lure the multinationals, markets involved in these arrangements

were lucrative: for instance, in 2006, Motorola generated nearly a quarter of its global revenue from its China operation, while Nokia, Qualcomm, and Lucent obtained over 10 percent of their incomes from China (Fan 2010).

An indigenous telecommunication equipment industry emerged in the 1990s, and leading Chinese telecom technology firms Huawei and ZTE began to challenge top global players in the 2000s. While the successes of Huawei will be analyzed in detail later, it should be noted here that the most commercially successful and technologically innovative Chinese firms, including Huawei and ZTE, were not grown out of the “Trade Market for Technology” policy scheme. The scheme’s direct beneficiaries are Sino-foreign joint ventures such as Shanghai Bell, once the largest switch manufacturer in the world, that ended up stuck in the switch business without developing the capabilities to move to the newer wireless technology. Exposed to similar management and incentive issues in Sino-foreign joint ventures (such as the semiconductor firms discussed earlier), Sino-foreign joint ventures in telecom equipment had difficulties in achieving technological dynamism as well.

The international background of the rise of Chinese telecom equipment manufacturers is rapid changes in technology and competitive landscape in the global industry. The Japanese technology giants such as NEC and Fujitsu were once formidable competitors in the fixed-line telephone technology in the 1980s and 1990s. But they were minor players in wireless technologies outside of Japan in the 2000s, partly because the Japanese communication technology evolved into distinctive technological systems which was highly advanced but incompatible with the international mainstream, a phenomenon that can be referred to as the “Galapagos effect” (Kushida 2011). North American and European multinationals dominated the global telecom-equipment industry at the beginning of the 21<sup>st</sup> century. In 2004, the global leaders were Ericsson, Alcatel,

Lucent, Nokia, Siemens, Motorola, and Nortel. Shortly in the time of a decade, this global ranking was completely shuffled. After a series of mergers and acquisitions, four of the largest companies, Alcatel, Lucent, Nokia, and Siemens, became one, the new Nokia Networks in 2016. Two companies dropped out: Nortel filed for bankruptcy in 2009 and Motorola sold its network business in 2011. Ericsson is the only remaining industry leader from a decade ago. During the same time, Chinese technology companies Huawei and ZTE rose rapidly in the ranking. By 2015, Huawei was already the world's largest telecom-equipment company by revenue (Fan and Gao 2016).

Many factors might have contributed to the decline of the North America-based telecom giants, including technology shifts, the global financial crisis, changing purchasing patterns among network operators, and the changes in relative importance of telecom markets in advanced and emerging economies. However, a group of scholars studying the global telecom industry for a long time has pointed out that financialization, or the overemphasis on financial distributions to shareholders at the expense of employment and investment, contributes to the demise of major Western technology companies, especially for North-American telecommunication technology companies such as Cisco, Nortel, Lucent, and Motorola. Lazonick (2009, 2014) criticizes the financialization of major technology corporations leads managers to channel valuable resources into stock markets through stock repurchases and dividends at the expense of investment in jobs, R&D, and productive capabilities. Financialization of the Western telecom-equipment companies might have undermined their capabilities to invest in critical new technologies and productive capabilities, contributing to their inability to adopt to changing technologies and market conditions, and making them vulnerable to challenges from new Chinese competitors (Carpenter et al 2003; Lazonick and March 2012; Bell et al 2013).

### *5.2.2 Roles of the government and changing policies*

There is little question that the Chinese government heavily intervened the industry during the takeoff of local telecom-equipment makers. It is however heavily debated on whether such government interventions in Chinese style is beneficial or detrimental. On one hand, pro-government scholars claim government involvement was essential to the domestic industry, giving credits to the Chinese government for providing dynamic and selective supports adapting to changing industrial conditions. Especially, it is said that, as Huawei and ZTE grew sufficiently large in early 2000s, the Chinese policy makers changed their minds from suppressing the private firms to supporting them (with subsidies and access to finance) (Fan 2006; Fan 2010; Fan and Gao 2016). On the other hand, critics argue the government support is generally wasting money on weak, non-innovative firms with close links to the states. The industrial policy has been inconsistent and confusing, creating unnecessary uncertainties for innovators (Fuller 2005; Breznitz and Murphree 2011). In this section, I provide an overview of industry policies in the telecom equipment sector over the last thirty years. While I do not attempt to systematically assess the effects of these policies (which is out of scope of this study), I find that the Chinese industry policy created both opportunities and obstacles in the rise of Huawei. Rather than cheerleading or condemning the role of the government, I find that the Chinese industrial policy was multi-faceted. On the supply side, the industry policy shifted from technology transfer/joint venture centered policies to promoting indigenous technology standards. On the demand side, the Chinese policy focuses on creating markets through government investment in infrastructure and several rounds of restructuring of the markets for telecom services. Since the Chinese joint-venture model has already been extensively discussed (in Chapter 4), I will focus in this section on the policies for market creation and standard settings.



### *Market creation policies*

The telecom equipment market in China is a government controlled market. Its rapid growth is driven by sustained government spending on infrastructure. The Chinese government investment in in telecommunication, transportation, and electricity infrastructure was regularly between six to ten percent of GDP during the 1980s and 1990s, within an economy registering double digit growths frequently (Naughton 2007, Lazonick and Li 2012). The way Chinese financed these investments changed over time. In the 1970s and 1980s, foreign aid played a key role in enabling the imports of advanced telecom equipment, especially large-scale public switches, to build up an early telecom network. By the 1990s, domestic financial institutions became the primary source of finance. China Development Bank led the lending to local telecom operators to finance their infrastructure investments in forms of low interest loans. Since the aggressive investments were often driven by political goals (such as several rounds of campaigns to connect every county, town, and village in the country in the telephone network within a set of time frames), their economic viability was not carefully considered. By the end of the decade, local operators had difficulties in repaying a substantial portion of the infrastructure loans, creating serious non-performing loans issues in Chinese state banks. Western critics often denounce those loans as subsidies to local telecom equipment manufacturers, but in China, these financing arrangements are generally seen as aids to local governments, and the distribution of the contracts are usually in a competitive way (Interview 41, 48; Sanderson & Forsythe 2012).

While the Chinese government is the sole owner and regulator of all telecom operators in the country, the market for telecom equipment was highly fragmented. Since the Reform, decisions to purchase have been decentralized to provincial, municipal and local telecom bureaus/operators. While national level purchases were mostly made with multinational corporations and their joint

ventures under the “Trade Market for Technology” agreements, the provincial and local operators usually had substantial freedom in choosing vendors based on their own budgets. The richer coastal province and urban operators can afford the prices charged by MNCs, but the poorer inland province and rural operators have more incentives to look for cheaper domestic products. It is generally believed that the inland and rural parts of the markets have been ignored by the MNCs because of their relatively low profit margins, left for the local manufacturers to grab (Mu & Lee 2005). Some scholars argue that the Chinese government through the Ministry of Post and Telecommunication (MPT) had consciously directed the local telecom operators to local manufacturers through a set of government-sponsored channels, citing the example of the Domestic Switch Customer-Producer Coordination Conferences (Fan & Gao 2016; Fan 2006). However, Huawei executives claim such interventions were meant to assist state-owned firms, such as Shanghai-Bell and Great Dragon, to secure orders (Interview 41, 48).

There were several rounds of restructuring of the state-owned telecom operators during the 1990s and the 2000s, but market fragmentation has not fundamentally changed. MPT was the sole owner and regulator of telecom operators until 1993, when a smaller state-owned China Unicom was created. Until MPT was dismantled in 1998, the MPT-owned China Telecom and its subsidiaries controlled most of the national market. In the mid-1990s, rural operators were given more preferential policies, including charging higher installation fees and surcharges, accelerated capital investment depreciation, and tax reductions and exemptions. Combined with low interest loans from state banks, local operators were empowered the capacity to invest in infrastructure. There were six operators nationally in the 2000s until they were mandated to consolidate in 2008 into three giant state-owned groups: China Telecom, China Unicom, and China Netcom. Each of the three are comprehensive operators providing both fixed-line and mobile services. Each of them

were given a different 3G standard licenses. Today the three state-owned groups still are structured through provincial subsidiaries, where local operators have retained power for a range of decision makings.

### *Standard-setting policies*

The origin of the Chinese telecom standard setting policies and practices can be traced back to the 1980s. In the early days of reform, decentralization of decision making and a lack of coordination resulted in a highly-fragmented telephone networks, in which local authorities imported telecom equipment from different foreign manufacturers using different proprietary technologies. These technologies were supplied by as many as eight companies, including NEC and Fujitsu of Japan, Lucent from the US, Ericson of Sweden, Siemens from Germany, BTM from Belgium, and Alcatel from France. These multiple standards and technologies co-existed on the telephone network were not always compatible, creating a set of technical complexities in interconnections. Moreover, the co-existence of multiple standards reduced the ability of the Chinese government to effectively leverage the size of its market and created barriers for local manufacturers. By the early 1990s, the government set national standards for voice, long-distance, and intelligent networks. Through a “Trade Market for Technology” arrangement, the government favors joint ventures between state-owned companies and multinationals, establishing companies like Shanghai Bell to manufacture switches with imported technologies conforming the local standards (Shen 1999; Mu and Lee 2005).

In the 2000s, in an awake of the role of technology standards in the telecom industry, the Chinese government pushed indigenous standards as an industrial policy to create advantages for local firms. Most notably, two high-profile standards are introduced: the indigenous 3G wireless

standard, TD-SCDMA (Time Division-Synchronous Code Division Multiple Access), and the indigenous wireless local network standard, WAPI (WLAN Authentication and Privacy Infrastructure). The TD-SCDMA was a competing standard with the WCDMA standard from Europe and CDMA2000 standard from North America, while WAPI was as an alternative to Wi-Fi and WiMAX standard. The WAPI technology has never been deployed: after a high-profile announcement on plans to enforce the standard for all WLAN devices sold in China in 2003, the Chinese government dropped the plan in 2006 facing opposition from trading partner nations.

The Chinese indigenous 3G mobile communication standard, TD-SCDMA, was accepted in 2000 as one of the three global 3G standards. Despite the strong lobbying of Datang, the state-owned telecom technology firm that developed the TD-SCDMA technology, the Chinese government did not commit to the indigenous standard in the first a few years. In September 2005, three renowned scientists wrote to the nation's top leaders to endorse the TD standard, urging the government to support national technology and industry. As China was about to embrace "Indigenous Innovation" as a national policy, a very high-level government official supported the promotion of TD-SCDMA as a policy priority (Gao and Liu 2012).

Even with high-level endorsement, the implementation of the TD-SCDMA standard was difficult and delayed. Comparing to established records of WCDMA and CDMA2000 standards, TD-SCDMA is a new standard with untested technology. None of the state-owned telecom operators were willing to implement TD-SCDMA for its unclear commercial prospects. While Datang was pushing the TD standard, Datang itself is too small to make enough investments to create a technology ecosystem. In the end, the adoption of the TD-SCDMA became a political issue testing the willingness of the Chinese government to push through its bureaucracy and state-owned industry in deciding who to bear the risks and costs of supporting the national technology.

It took almost four years to select the operator for TD-SCDMA, which also delayed the whole process of adapting *any* 3G standard in China. By January 2009, the Chinese government eventually issued 3G licenses to domestic operators. China Mobile, the largest and most profitable among three operators, were designated to take the TD-SCDMA license, as China Mobile was considered most capable to bear potential risks and costs for the new technology (Interview 3; Breznitz and Murphree 2011).

The implantation of the TD-SCDMA standard is one of the most influential and controversial technology policies in China. In 2013, China Mobile announced that it would no longer further invest in TD-SCDMA infrastructure, which is only five years after the initial commercial deployment. China's neoliberal economists criticized TD-SCDMA technology and policy as a huge government waste, costing over RMB200 billion only to create the world's shortest lived 3G network (Tan 2014). Defenders of TD-SCDMA argue that the TD standard policy created an opportunity for Chinese domestic companies to learn and upgrade technology otherwise impossible. They cite that the benefits of TD-SCDMA include eliminating TD-SCDMA technology licensing fees for domestic manufacturers, the ability for Chinese manufacturers to negotiate lower fees for other standards, and the spillover effects to other technology sectors such as smart phone and IC design (Fan and Gao 2016, Fan 2006).

The opportunity for China to use standard setting as an industrial policy was perhaps unique in history. By the 2010s, with the transition into 4G era, competing standards have converged under LTE (Long Term Evolution) technologies. The window of opportunity for any nation to exercise indigenous telecom standards policy seems to be increasingly narrow. By this time, China already built one of the most competitive telecom technology industries in the world.

### *Section summary*

In this section, I provide an overview of the industry and policy background for the growth of Huawei. In the global telecom technology industry of the past thirty years, rapid technological changes and shifts in business models led to relative declines of the Western and Japanese multinational corporations, especially those operating in the hardware and manufacturing spaces, creating opportunities for the global expansion of the newly emerged Chinese companies. However, to seize these opportunities, companies like Huawei had to succeed first in the domestic markets, where multinational corporations created high entry barriers. Those barriers include not only superior technologies, but also political and institutional barriers: as the “Trade Market for Technology” agreements bind the interests of elites in the state industry with those of the multinationals through their joint ventures.

Domestically, Chinese government involved heavily in industry formation through a combined effort of sustained spending on telecom infrastructure and interventions in market and industry structure. It must be noted that the intention of the Chinese industry policy was to support the state industry and its National Champions. However, the industry policy was carried out in an inclusive manner, such as that the sustained demands benefited all domestic producers, and that technology diffusions from state research programs and operations of the multinationals were widespread. Eventually, the more competitive non-state Huawei succeeded in this environment, a process which I am going to analyze in detail.

### 5.3 Technological Innovations and the Growth of Huawei

#### 5.3.1 *Early Days of Huawei and Innovations for Rural China*

Huawei was founded in 1987 in Shenzhen as a vendor of telecommunication equipment, primarily circuit switches in telephone networks. The market opportunity was created by the Chinese government's investment in telecommunication infrastructure and its demand for home-grown switch technology in the mid-1980s. At that time, more than 200 new companies entered the telecom equipment industry. Initially Huawei imported private branch exchange (PBX) switches from nearby Hong Kong, just across the border. But by providing superior customer service and, from time to time, modifying the switches according to specific needs of its Chinese customers, Huawei emerged as a technology-oriented company rather different from its peer importers (Interview 40, 47).

Huawei started developing its own switches not long after its opening. According to senior Huawei executives, in the early days the company's growth had been held back by suppliers, i.e., the Hong Kong-based original manufacturers, which motivated Huawei founder Ren Zhengfei to develop in-house technology and products (Interview 47, 48). Huawei's first product was a 500-line per unit PBX model, HJD48, possibly resulting from an unofficial collaboration with Tsinghua University researchers to reverse-engineer imported models. An improved model, "JK1000" with approximately 1000-line per unit, sold well and helped Huawei to establish itself in the domestic market. HJD48, JK1000, and several Huawei's early products, while being commercially successful, were small-scale switches based on the older analog technologies. Ren was aware that relying on the older technology would not lead Huawei to succeed in the fierce price-based competition with other domestic startups. Thus, Ren determined from early on to enter the space of higher-end, large-scale digital switch systems, a highly profitable market dominated by

multinationals and their Chinese joint ventures in the 1980s. Because of its status as a private company, Huawei was unable to take the international joint-venture (JV) route to importing and absorbing technology as the privileged state-owned firms did. Instead, Huawei had to develop the digital switch technology in-house.

In 1993 Huawei released its first in-house developed, large-scale PDSS (Public Digital Switching Systems): The C&C08 program-controlled switches. The C&C08 series switch achieved a capacity of 2,000 circuits in 1993, and was further improved to 10,000 circuits in 1995. In developing C&C08, Huawei was betting heavily: it not only invested all its profits from selling analog switches, but also borrowed heavily from semi-legal high-interest lenders at a time when it was difficult for private firms to access state bank lending. Fortunately, Huawei and a few other Chinese manufacturers substantially benefited from the indigenous development of a PDSS prototype (the “HDJ-04”) by the Chinese public research institutes (Interview 51).

The People’s Liberation Army (PLA) Zhengzhou Institute of Information Engineering was the army-affiliated institute that developed the PDSS prototype in the late 1980s. At that time, a dominant design of PDSS by multinational telecom-equipment companies (i.e., AT&T, Nortel, Siemens, Ericsson, NEC, etc.) was to use special-purpose, custom integrated circuits (IC) and boards to deliver switching functions. Such a design idea could be seen as a continuation from making analog devices. Those designs use a large number of low-integrated, custom-designed special-purpose chips dedicated to performing specific tasks in the switch. From a traditional engineering point of view, such design increases stability speed for using dedicated chips, which is the top concern for any infrastructure equipment. Moreover, from a commercial perspective, the amount of proprietary knowledge involved in custom chip designs protects innovation and fends off competition. Japanese manufacturers were particularly good at such designs as they



accumulated strong capabilities in analog board designs. The Chinese researchers in the 1980s followed an alternative design idea. They developed a computational architecture to build PDSS switches using a small number of mass-market, general-purpose chips to deliver the switching function through software controls – an idea of designing the PDSS more like a computer rather than a traditional telecom equipment (see Shen (1999) for a detailed comparison of the technical characteristics of HDJ-04 and imported switch technologies). The HDJ-04 design was a less efficient and stable solution, yet it was much cheaper and it did not require advanced chip technology and capability which China was lacking and the exports of advanced semiconductor equipment to the Communist China were heavily regulated (See Chapter 4 for China’s history of developing semiconductor technology). In retrospect, the computer-based architecture design later became the dominant design as the advances in computer chips enabled such designs to be more powerful and flexible but at lower costs than the traditional less-integrated equipment. Thus, the computer-based architecture is a case of “disruptive innovation”, a term Clayton Christensen uses to describe the phenomenon of a new, initially inferior technology that improves over time, eventually displacing existing technology, markets and firms (Christensen 1995).

In the 1990s, the diffusion of the HDJ-04 design and relevant knowledge enabled the emergence of Chinese manufacturers with their lower-cost PDSS designs and products. Driven by a strong domestic demand for telecom infrastructure equipment, these Chinese newcomers grew rapidly. Most notably four Chinese companies grew to become leading domestic players, including state-owned Great Dragon Telecom (a spinoff from the PLA Zhengzhou Institute of Information Engineering), state-owned Datang Telecom, Zhongxing Telecommunication Equipment (ZTE), and Huawei. The four companies were frequently collectively mentioned together as “Juda Zhonghua” (巨大中华, literally it means “Greater China”) by Chinese media. Among “Juda

Zhonghua”, the non-state Huawei and ZTE, grew into the most successful two. Huawei, in particular, had more successes in profiting from the PDSS technology through a strategy to access the underserved rural markets.

In the 1990s, the coastal Chinese cities were the most profitable markets for multinational companies and their joint ventures with state-owned Chinese firms. The rural and inland markets were deemed as somewhat undesirable for their comparatively thinner profit margins and difficult working conditions. The rural market even received considerably less attention from Chinese policy makers, who had actively used the high-margin urban markets to trade technology with foreign firms or to protect state industry. Nonetheless, Huawei and ZTE thrived in the difficult but less regulated rural and inland markets. Huawei was able to penetrate this market through a combination of dedicated employees and technological innovations. First, Huawei sent highly motivated employees to work closely with the rural telecom operators on site. In the late 1990s, for example, Ericsson had only four employees working in the northeastern Heilongjiang Province, while Huawei had over 200 people (Interview 51). Those Huawei people were not simply salesmen or saleswomen, but rather most were engineers active in Huawei’s R&D activities. When developing face-to-face close relationships with customers, those engineer-turned salespeople channeled critical information about the customers’ demands and issues back to Huawei engineers in Shenzhen. In turn, Huawei’s R&D organization used such information to prioritize resource allocation and problem solving. Second, in solving the rural operators’ issues, Huawei had introduced a stream of innovations into the C&C08 series and gradually improved quality. Some of these innovations are minor improvements in a technical sense, such as modifying the device to shield from the rampant rats in the countryside or putting in extra batteries to prevent damages from unstable power supply. These seemingly small improvements solved major operational issues

in the rural areas (Interview 48, 52). Nevertheless, in some cases, Huawei was an early adopter of various new ideas and technologies, including modularization in network building.

Modularized network and optical fiber connections were two critical new technologies Huawei brought to the Chinese rural market. At that time, the conventional telecommunication network structure favored the construction of large hubs housing clusters of switches to serve tens of thousands of telephone lines, connected to the hub with copper wires. To deploy telecom infrastructure in rural areas, there is a major challenge: long-distance copper wire connection is costly to construct and delivers poor voice quality because of signal degradation. To reduce the use of copper wires, a switching hub has to be constructed relatively close to the residents, which only makes economic sense when a switching hub can serve thousands of users in densely populated areas. It is difficult to justify a large investment such size (costing hundreds of thousands of yuan in mid-1990s) to serve only a limited number of lower income rural subscribers in the rural areas. Huawei's solution was to modularize the switch and bring smaller switching hubs closer to the subscribers. Partly thanks to the computer-like architecture of the C&C08, Huawei was able to break down a large switching equipment with more than 10,000-line capacity into switch modules with capacity of thousands of lines. In this way, Huawei can construct smaller switch hubs very close to the subscribers with lower initial cost, but more switching modules might be added later for the increased number of users. Those smaller hubs are then connected back to central hubs with optical fiber connections, using digitalized signals to ensure speed and quality in long-distance transmission. These two innovations thus allowed Huawei to offer a system-wise lower-cost, more flexible network equipment to rural operators with small budgets (Interview 51, 52).

To be fair, Huawei did not invent either modularization or fiber network. According to Huawei executives, both technologies were matured enough to be deployed in the late 1990s

(Interview 51). Yet, most multinational companies were not incentivized to make efforts to integrate these technologies into innovative products to serve a rather marginal market in rural China. It might also be a pure luck for Huawei to lead in fiber network technology, as several senior Huawei executives point to that the two lead engineers in designing the C&C08 series had a background in optical fiber communication. Nevertheless, Huawei's experience in making switches with those innovative technologies showed that its success was probably more from its innovative organization rather than the technology itself. The early batches of the C&C08 series PDSS were very buggy: Huawei sent a great number of engineers to stay at customer's sites to solve issues in real time for weeks or even months upon initial installation. These service engineers serve as another channel for information gathering for R&D. Unlike multinationals that charge high service fees, Huawei did those services for free. Luckily, Huawei was in a market with way more demand than supply. As a result, their profit margins were high enough to not only sustain their business but also pay higher than market wages to the employees to keep them incentivized and mobilized in harsh working conditions. In the end, these bug-fixing experiences became a learning process for Huawei to improve its quality, and in many cases, relationships and trust were built between Huawei and the operators. Such relationships in turn encouraged the operators to experiment with new features and technologies with Huawei<sup>20</sup>.

The continuous improvement in the C&C08 series made it a very competitive product by the end of the 1990s. A senior Huawei executive claimed during the interview that the unit cost of C&C08 switch was equal or higher than equivalent switch products from international competitors, but telecom operators were attracted to Huawei by the lower initial costs in network building and

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<sup>20</sup> In interviews, Huawei executives admitted the impacts of bug-fixing process on customer relationship can work in the other way: some operators distrusted Huawei's quality for an extended period after unsatisfactory experience with early products (Interview 51).

the flexibility to expand capacity later in using the C&C08 (Interview 51, 52). Huawei's C&C08 also had the advantage of being a newcomer in a time when the product cycle was relatively long. As the C&C08 uses newer, better-integrated chips, it can be built smaller and uses less power while Huawei's competitors were slow to migrate to newer technologies, at least in their operations in the Chinese markets.

In around 1997 and 1998, Huawei began to penetrate the Chinese urban markets, starting from business users such as universities and hotels. At the same time, Huawei started to internationalize by selling switches in other developing country markets, including Pakistan, Russia and Thailand. A decisive opportunity for Huawei to become a leader in the Chinese market occurred in 2002 when the central government determined to break up the state-owned monopoly China Telecom into two regional operators: a new China Unicom in the north (by merging the old China Unicom and parts of old China Telecom's regional operators) and a new China Telecom in the south. This move created a set of technical issues new to China, including how to connect phone calls between two operators, and how to bill the transactions for inter-network calls, etc. Huawei captured the opportunity by sending its best engineers to work closely with the state technology standard agency, China Telecommunication Research Institute. By actively engaging with government officials and providing various technical inputs, Huawei influenced the process of technical standard setting directly and indirectly. As a result, Huawei was among the small number of manufacturers that were able to provide equipment conforming to new standards ahead of foreign competitors. By the early 2000s, Huawei had become a market leader in the Chinese fixed-line telecom industry.

### *5.3.2 Innovation in Wireless Network and Rise in Global Competition*

From the mid-1990s to at least 2005, the C&C08 series PDSS was Huawei's main sources of revenue (Interview 46). During this time, Huawei made investments in three areas. First, Huawei expanded the sales of its switches in emerging and developed markets in Asia, Africa and Europe, establishing an early global distribution network. Second, Huawei used the profits to fund technology and product development, expanding into related markets and technologies, including wireless network, data network, optical fiber technology and IC design. Finally, Huawei spent tens of millions of dollars on modernizing management practices and establishing management systems and processes, such as Integrated Product Development (IPD) process, to control its R&D, manufacturing, and marketing processes. The takeoff of Huawei's wireless network business eventually allowed the company to become a global payer.

As early as 1995, Huawei started to be involved in wireless technology development. The development work started with wireless access equipment, which was primarily used in telephone networks in mountainous areas where wiring fixed-line networks is difficult and costly. But Huawei quickly leveraged this expertise to move into modern cellular network technology. In 1998, Huawei had its GSM network equipment certified. But Huawei was already late in the wireless network market, even in China: the company tested its GSM base stations in Inner Mongolia as no operators in coastal or central provinces were interested. In 2000, Huawei started its CDMA line of equipment to catch a market suddenly emerged as the regulator designated China Unicom to build a CDMA network to compete with China Mobile's GSM network. Although Huawei was remarkably fast to respond to this opportunity, the company had been a rather marginal player in the whole second-generation (2G) wireless technology (including GSM and CDMA) market.

Nevertheless, Huawei was investing heavily and betting on catching up in the 3G era, particularly in building capabilities around the European standard of WCDMA.

As mentioned earlier, in early the 2000s, the most important debate in the Chinese telecom and industry policy was the formulation of an indigenous standard of 3G technology, which later was known as the TD-SCDMA standard. While the overall impact of the TD standard was perhaps very complex to evaluate and beyond the scope of this study, a direct consequence of the policy was a severe delay in issuing 3G licenses to the Chinese operators. Major Chinese operators were not issued 3G licenses until 2009, eight years after the three major 3G standards (WCDMA, CDMA2000, and TD-SCDMA) were instituted.

Because there was no market for 3G networks in China, Huawei looked for buyers of its mobile network technology abroad. In 2001, Huawei started to enter the European market. At that time, the company already had some experience of doing business abroad, mainly from selling its C&C08 switches in less developed markets, such as Pakistan, Thailand, and Russia (Interview 46). Its first sales in Europe were wireless base station products to smaller operators in the Netherlands and optical network (SDH) products to Germany. Soon after, Huawei built networks for Neuf, a small French operator. In 2003, Huawei found its first, perhaps unexpected, customer for its WCDMA technology in the United Arab Emirates, making UAE the first Arab state to build 3G networks. In December 2004, Huawei won its first major contract with the Dutch operator Telfort to build a WCDMA network covering the Netherlands. In 2005, after two years of certification process, British Telecom (BT) designated Huawei as a preferred supplier for its 3G network. Soon, Huawei signed supplier agreements with Telstra, Telefónica, and Vodafone. By 2008, Huawei had won more than a hundred HSPA/WCDMA contracts, with major European operators including Deutsche Telekom, Vodafone, British Telecom, Telefónica, and France Telecom (Orange). In

2009, Huawei worked with the Scandinavian operator TeliaSonera to demonstrate the first commercial LTE network in the world, and started to construct a LTE network for the Norwegian operator Telenor. By 2010, Europe became Huawei's largest regional market in terms of revenue.

Huawei's route to success in the European mobile network market resembled a remarkably similar strategy that it had used earlier in fixed line networks in China: a disruptive growth trajectory starting from a marginal market combined with technological innovations to meet underserved demands. For the European market, the technology in question was the so-called distributed base station which Huawei introduced in 2004. The base station is the interface equipment that transmit wireless signals and connect to the wired network (such as a radio tower). In the early 2000s, the European operators were beginning their upgrades from 2G to 3G networks. European network operators, particularly those smaller ones that were Huawei's early customers, found it costly to construct new base stations in the densely populated European urban environments. According to the recall of senior Huawei executives, Huawei's product managers brought in the R&D engineers on site to understand this issue and initiated the development of a solution. The result was that Huawei was first to implement a commercially viable distributed base station design. The distributed design breaks the base station into two parts: the base station server (or baseband unit, BBU) and the remote radio head (or remote radio unit, RRU). The base station server and the remote radio head can be separately installed and connected with optical fiber. The radio heads could be placed on roofs, while the base station servers are kept in buildings, thus the distributed base station design largely reduces the need to construct special-purpose radio towers and electrical rooms. Therefore, the distributed base station has a disruptive economic effect as it reduces capital cost to allow smaller operators to compete more effectively with the larger ones. While the design idea of a distributed base station was not entirely new, its implementation in a



commercial setting has technical challenges. Compared to lab environments, these challenges are such that the antenna/RRU needs to be built smaller, more efficiently, and more durably to adapt for more diverse environments; the BBU needs to have more processing power and be efficient, using chips at a higher level of integration. Through solving these engineering challenges, Huawei demonstrated its technology capabilities accumulated from developing switches, fiber network, IC designs and engineering works. Successes in the distributed base station also helped Huawei to catch the attention of the larger European telecom operators (Interview 49).

The major technological innovation that put Huawei in a position of industry leader is the SingleRAN (Single Radio Access Network) technology. SingleRAN, as its name suggests, is a technology solution (or put it in another way, a bundle of technologies) that allows one set of telecom equipment to simultaneously provide wireless networks in multiple standards (i.e. 2G, 3G). In 2006, Huawei began to engage major European operators in the hope to tap into underserved markets. The engagements resulted in contact with a Spanish team of telecom experts working for Vodafone, the largest European operator at that time. Huawei invested substantial resources in maintaining this relationship by setting up a collaborative organization named Mobile Information Center (MIC) in close adjacent to the Spanish team's location. High-level Huawei directors, experts and system engineers went there to work with the Vodafone team, often for a tenure of two years. At the Spanish MIC, Vodafone experts raised issues and ideas in telecom operations, while was is the SingleRAN technology, an idea that were rejected by most telecom equipment makers for its lack of technical feasibility.

The problem that SingleRAN was to address comes from the transition from 2G to 3G networks. The early 3G network base stations were separate sets of equipment operating independently of existing 2G wireless infrastructure. That meant, to provide 3G along with existing

2G networks, the telecom operators had to construct separate facilities, buy separate equipment, operate separate network systems, and maintain separate operating workforces. The telecom operators had a strong incentive in obtaining a unified system that could provide multiple standard networks on a single set of network equipment. In theory, ideas of such a unified system solution based on software defined radio (SDR) can be traced back to researches funded by US Department of Defense in the 1970s. SDR uses the means of software on a computer system to replace components that are typically implemented through hardware, which is the function of modulating and/or demodulating radio signals, to be specific. SDR is not particularly difficult to realize in a lab setting when there are abundant computational powers without concerns of efficiency and stability over long hours of operation. In an industrial and commercial setting, however, any practical SDR-based systems has to overcome two challenges. The first challenge is technical: the SDR-based base station has to be built small, efficient and reliable enough. That can be done through a combination of developing computer chips with higher level of integration to deliver more processing power at lower energy uses and developing algorithms to make more efficient software. The second and more difficult challenge is a technology standard issue: the 3G wireless standards are mainly set by in a collaborative way by the 3rd Generation Partnership Project (3GPP), an international body comprised by member companies, research institutes, government agencies, and other organizations. The way 3GPP operates means that standards and protocols in the 3G network are defined collectively. Thus, any SDR-based technology has to successfully deal with all sorts of co-existence and co-operation with other protocol technologies. It effectively means developing SDR technology that involves setting new standards in terms of how multiple protocols should work together. As one Huawei executive stressed, “Dealing with technical issues with such complexity cannot be solved by paperwork, nor can salesmen or project manager have

a full understanding, it has to be (R&D engineers) sitting together with the clients [to communicate effectively]” (Interview 49).

In 2006, Huawei was perhaps in a unique position to push the SingleRAN technology: Huawei was a company with substantial technological capabilities but as a newcomer to the European market, it had a strong interest in disrupting the status quo. That being said, Huawei had committed substantial resources to developing the technology. Top-level experts and R&D engineers were sent to Europe to work closely with the telecom operators throughout the process of concept development, design, prototyping, pilot production, and commercial deployment, which lasted about two years. By the end of 2007, Huawei brought to the market the first commercial base station with SingleRAN technology, “S1”. The S1 was available for the mass market in Europe in 2008, giving Huawei a competitive edge ahead of competitors for 1.5 to 2 years. Meanwhile, Huawei worked closely with Vodafone to push their collectively developed SDR technology as the industry standards for SingleRAN in 3GPP. As a result, Huawei reaped huge gains from its investment in the SingleRAN technology: Huawei’s global market shares in wireless infrastructure grew from 10% in 2008 to 30% in 2015.

### *Section summary*

In this section, I documented Huawei’s transformation from a private start-up to a leading multinational corporation within three decades, emphasizing key technological innovations in digital switch and wireless base stations that enabled the company to compete and succeed in key markets. In the literature, there is some documentation of Huawei’s innovation in digital switches (e.g., C&C08) (Feng 2010), but little is known about the innovations in wireless base stations (e.g., SingleRAN). However, these are important examples of how emerging Chinese firms innovate for

domestic and international markets. By describing Huawei's innovation process, I have shown that Huawei's success did not result from imitating foreign technologies or selling cheap knockoffs, as conventional wisdom would suggest. Instead, Huawei succeeded through developing new technologies, often in the form of architectural design change, and disrupted the industry by moving from low-cost segments to high cost ones. Publicly funded researches and user knowledge are at least as important a source of knowledge for Huawei as spillovers from competitors. In the next section, I will discuss how Huawei is able to achieve these innovations and what might be the limitations to its model.

#### **5.4 Huawei's "Three-Pronged Investments"**

Technological innovations in modularized digital switch design, distributed base stations, and the SingleRAN technology were critical milestones in Huawei's transformation from a private startup into a global telecommunication technology giant in the 2000s. These innovations, however, should be seen as outcomes of the company's long-term accumulation of innovation capabilities. Over the course of its growth, Huawei consistently invested 8% or more of its sales into R&D (Table 5.1). In selected years, the R&D investment is more than 10%. Such is a level of commitment to technology development rarely seen among peer Chinese companies during the same period. As we observed in the case study, Huawei's R&D investment has created an effective system of technology accumulation: Huawei's later innovations in wireless technology were built on earlier experiences in fixed-line networks and accumulations of knowledge in key technologies such as signal processing, fiber network, and IC designs. In this section, I will first explore *why* and *how* Huawei transformed R&D investments into sustaining innovation capabilities.

In *Scale and Scope: The Dynamics of Industrial Capitalism*, Alfred D. Chandler made the statement that the growth of modern industrial enterprises depends on “three-pronged investments” in distribution, large-scale production facilities, and professional management, allowing the industrial enterprises to exploit the potential economies of scale and scope of the new production technology (Chandler 1990). Management scholars theorize these types of investments as investment in complementary assets, which are the necessary complementary capabilities in order to appropriate gains from innovations (Teece 1986). In the case of Huawei, its heavy investment in R&D created a new challenge, similar to the utilization of large-scale production technology in earlier era as the innovative firm has to exploit the economic potential of invested technologies to recoup high costs. The challenge is different as investment in R&D allows firms to exercise control on the nature and direction of technology being developed.

The growth and innovation of Huawei, I argue, is built on “three pronged investments” to control and appropriate from its high R&D investment strategy:

- Investment in developing relationships with customers and acquiring user knowledge for technology development;
- Investment in the accumulation of basic knowledge and know-how that are transferable across product lines and technology standards;
- Investment in a capable workforce that is motivated to develop new knowledge and utilize the company’s capabilities, accumulated both internally and acquired from outside, to rapidly respond to volatile demand changes and technology opportunities with reduced time to market.

These three-pronged investments allowed Huawei to exploit the economic potential from the high costs of investing in a knowledge base. Because of rapid technological changes in the information

and communication industry, especially generational iteration and competing standards, investment in basic knowledge not bounded to specific products or standards is necessary to adopt and lead changes. Similar to investment in distribution network for manufacturing enterprises, investment in customer knowledge helps to secure the market. Moreover, utilizing customer knowledge reduces uncertainties in the innovation process.

#### *5.4.1 Investment in User Knowledge*

In the case study, I show that Huawei has a long-standing tradition of developing deep knowledge of its technology users, i.e. the telecom operators, in understanding their needs and technical issues to facilitate Huawei's own innovation process. This technical and market knowledge from users led Huawei to innovate in a specific direction: modularized, software-heavy telecom systems as in its three major technological innovations (C&C08, distributed base station, and SingleRAN). I also show that Huawei has developed sophisticated organizational arrangements and capabilities to allow information to flow from the user side to its engineering process. These arrangements evolved from sending lots of engineers to customer sites in the 1990s to formalized co-located co-innovation centers with telecom operators in the 2000s.

A closer look at Huawei's history shows that the origin of Huawei's way of engaging technology users was an early response to the necessity of profiting from large investment in R&D. Several senior Huawei executives confirmed that there was a crisis in the early 1990s from inability to profit from technological investments. At the startup stage, Huawei is an engineer-dominated company. Ren Zhengfei gave substantial freedom to the engineers in determining technical details, as Ren was a civil engineer who knew little on how to engineer communication equipment. It is openly acknowledged in Huawei that "the boss does not know the technology". In early days,

Huawei engineers often invented whatever products and features they perceive new and useful, and salesmen then tried to figure out how to sell those inventions. Not surprisingly, in the transition economy in the early 1990s, not many engineers had much sense of the actual market. In 1993, Ren held a company-wide meeting that Huawei would be running out of cash in a few months, and therefore every engineer had to find market for their own products. In the meeting, being held in an outdoor setting, engineers were asked to take their unsalable inventions with them and took photos – a form of public shaming intended to remind the engineers of their jobs as creating revenue-generating products<sup>21</sup>. After the meeting, engineers were dispatched to telecom operators in all parts of the country as sale agents. Not only the revenues brought back with the engineers eventually saved Huawei from bankruptcy, but also since then the practice of job rotation of R&D engineers to sales functions persists in Huawei. It evolved to become part of the corporate ladder: working in sales is part of route for an R&D engineer to ascend to a manager position.

But how did Huawei make it work by making engineers as salesmen? Consider that there are rather different norms, culture and codes of conduct between the two professions of engineering and sales. Not to mention that it seems to be rather wasteful way of utilizing the skills and experience of seasoned engineers.

Li Ke, a senior executive described his experience in the mid-1990s: As a top graduate student from the University of Electronic Science and Technology of China in Chengdu, a premier national electronic engineering school, Li joined Huawei in 1995 at a salary level he described as comparable the pay in major multinational corporations. After working on the R&D part of a testing equipment for a year, Li was sent to sell switches in Northwestern China. In a single year,

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<sup>21</sup> A photo of the meeting was shown to me during my interview (Interview 2015/07/18). There were several engineers who later became top management of Huawei. It was considered a “friendly insult” to the engineers.

he visited over 600 counties. Li described the process to develop relationships with the local telecom bureau operating at the county level:

“I might spend hours or days there. In the end of the day, I was called to go upstairs to the bureau director’s office, then he asked for help because he had difficulties in calculating telephone bills. Of course, I would help him” (Interview 51)

As the relationship deepened, the local telecom bureau asked for help on much more difficult issues.

Another senior engineer, Li Xiangbin, who joined Huawei in 1993, described the process of solving a complicated technical issue, involving Huawei engineers moving back and forth and between Huawei and client sites for experimenting and testing. In the mid-1990s, a telecom bureau in Shanxi Province asked Huawei to provide unified control systems as the client purchased equipment from several different vendors. The telecom bureau might not have been technically sophisticated, but the people there had deep technical understanding and imagination. While solutions to such problem might not be practical even today, as Li Xiangbin acknowledged, he still agreed to work on the project partly due to “no experience” and partly to a culture that those Huawei engineers are pressured not to say no to customers. The engineer spent months and went back forth between Shenzhen and Shanxi until both parties concluded that it was not a practical idea. However, Li Xiangbin concluded that this experience strengthened relationship between the company and customer, and he personally learnt a broader range of knowledge including telecom protocols and programing skills during the process (Interview 48, 52).

Both Li had observed that, the close relationship between engineer and operator was effective because it was part of the organizational learning process. Li Xiangbin observed that in its early days before Huawei implemented formalized routine and procedures, requests from the



users were often used as signals to guide priorities in the R&D works. Engineers were also very responsive to customer requests on short notice. Here, Li Xiangbin expressed concerns that as Huawei became a large organization with rigid procedures and routines, it had become less flexible and responsive than it was in the early days (Interview 52). Li Ke made an even stronger argument that the continuous improvements through solving problems for the operators was the key factor that made Huawei's C&C08 digital switch, which was a latecomer to the market and hardly top quality upon initial release, to become a success (Interview 51).

By the 2000s, as Huawei grew to be a large organization, this type of frontline sales engineers directly calling R&D departments to solve specific problems were phased out. Instead, Huawei instituted a system of procedures and processes adopted from IBM called "Integrated Product Development", or IPD, to handle the information flows within its organization. In interviews, Huawei employees often mentioned that higher-ranked directors and R&D managers would show up on customer sites to facilitate information exchange and problem identification. It seems to be a twist to the IBM version of IPD, as in a hierarchical Chinese organization, higher-ranked managers would have the authority to direct attention and set priorities that lower-ranked sales and engineers cannot. Such arrangement works as Huawei executives and managers today still come from the ranks of R&D and production engineers (rather than MBAs) who have technical understanding of the issues. Additionally, Ren Zhengfei continued to use his influence in Huawei to frequently organize campaigns that promoted the roles for front-line sales personnel and engineers. Ren openly declared, "Let the people who can hear the thunder of guns make the decisions" (Ren's remarks on Huawei's award ceremony in January 2009, cited in Feng (2010)).

Why was the strategy to invest a great deal of human resources to establish relations with telecom operators and secure their knowledge effective in supporting Huawei's growth? One

might immediately think of the role of “Guanxi” or relationship in lubricating business dealings in China. On one hand, in the case study, Huawei executives described the way they developed relationships with local operators is indeed personal in nature, fitting the common sense of “Guanxi” that in China business builds on interpersonal friendship, trust, and bonding. On the other hand, “Guanxi” would not explain why Huawei opted to have engineers as the sales agents, who are apparently more expensive and less skillful in cultivating relationships than the regularly trained salesmen. Furthermore, “Guanxi” would not explain Huawei’s relations with European operators either, where the norms of doing business is supposed to be Western.

From the innovation perspective, Huawei’s relations with telecom operators could bring in valuable information to direct its R&D efforts. Innovation theories suggest that moving the locus of innovation closer to customers, in general, is usually due to the existence of “sticky information”, that is information that is costly to acquire, transfer, and use in a new location (Von Hippel 1994). There are three types of situations that led to the stickiness: there was a great deal of information, especially contextual and tacit information, that needed to be transferred; the acquisition of information requires related information and skills; and the existence of technological gatekeepers.

In the case of the Chinese switch market in the 1990s, there are several factors that might result in a “sticky information” situation at the sites of local operators. First, the operator’s issues can be local ones that require contextual knowledge to understand, due to varying geographies in China’s large territory and uneven development. Second, the staff at local operators tends to have low levels of education and training, lacking capabilities to identify and properly communicate issues to equipment suppliers. Third, there is often a trust issue between local operator staff and service engineers, as operators who are nominally officials at local telecom bureaus were afraid to lose face by asking simple questions. As shown in the interaction between Huawei engineers and

telecom officials, it takes personal relations to facilitate information exchange on simple issues. In committing sizable engineering workforces at user sites, Huawei obtained a competitive advantage over its multinational/JV competitors. In the 1990s, Chinese JVs undertook little R&D work but focused on localization and production, while leaving much R&D and design works to foreign partners. Local engineers had little influence on the design and improvement of new equipment. Located in major cities, JVs' service engineers were expensive and slow in responding to local operators, and usually lacked the time and opportunity to develop personal relationship with operators (Feng 2010). Thus, while the structure of JVs limited their abilities to improve and iterate designs for the local markets, Huawei excelled in this regard through a deliberate strategy.

As Huawei grew to become a multinational firm, the company's strategy to engage users in Europe and other advanced markets could be seen as a continuation from its earlier trajectory. The European operators have strong capabilities and operate networks with the latest communication technologies, and thus they can identify advanced issues and lead Huawei towards developing cutting-edge technologies. The question is, how did Huawei develop the capabilities to work with the leading users?

#### *5.4.2 Investment in Technological Accumulation*

Developing goods and services at technological frontiers requires far more than solving problems for users. In the telecommunication technology industry, adapting constant evolving technology standards requires capabilities in combining hardware and software. While Chinese manufacturers are known to be good at making small tweaks to cater to consumer tastes, those usually tend not to lead to technological breakthrough. The type of architectural innovation Huawei led requires deeper understanding of the underlying sciences and technologies in

communication equipment. Huawei's early sources of the digital switch technology comes from indigenous public research institutes, but internal accumulation of knowledge became more important as the company grows. Huawei's history of developing wireless technology illustrate the company's strategy in investing in the intangible underlying knowledge.

From the mid-1990s to the mid-2000s, Huawei had been funding the R&D of wireless technology using revenues generated from its other products, despite constant setbacks. Huawei was too late to the 2G market: when its GSM technology matured in the late 1990s, there was so few markets in China to grab that the company had to do a pilot project in Inner Mongolia, a remote and economically under-developed province. Between 1998 and 2004, Huawei invested in over 3,000 engineers and over RMB1 billion in WCDMA and soft switch technology. The 3G technology that cost Huawei millions of dollars to develop also had a market access problem, but this time it was because the government maneuvered the process of national standard setting and delayed issuing 3G licenses in seeking an advantage for the domestic industry (Interview 46, 49).

Business cycle and international markets did not favor the timing of Huawei's entry into the 3G wireless technology. In the early 2000s, the telecom industry was regressing from the aftermath of the dot-com bubble. With network operators around the world reducing capital expenditure, major multinational telecom equipment manufacturers including Siemens and Nortel responded by cutting R&D budgets and laying off people. Huawei, to the contrary, maintained its personnel and R&D efforts, financed through selling off company-controlled financial assets, such as stocks invested in energy business (Interview 50).

The Chinese political economy did not favor Huawei's strategy and choice of technology trajectory, either. In wireless technology, Huawei chose to invest in GSM and WCDMA technologies, both of which were regarded as the mainstream technologies initially developed and

promoted by the Europeans and later became the most widely adapted standards worldwide. As newcomers to the telecom industry, the Chinese manufacturers had no apparent advantages in developing and competing in WCDMA technology. But the development of the Chinese indigenous standards provided both opportunities and uncertainties. In the early 2000s, as the Chinese government experimented in national standard setting, there were quite a few uncertainties in terms of when the 3G license would be issued and the market would be launched, to what extent the Chinese government would support its ingenious standards, and thus how markets would be divided among competing 3G standards. An innovation strategy to reduce political uncertainties should be investing in the Chinese TD standard, anticipating at least some protections from the government. Indeed, most Chinese telecom equipment manufacturers, including ZTE and Datang (which led the development of the Chinese TD standards), concentrated their R&D on the indigenous standards.

Huawei's strategy in investing in WCDMA was not because lack of profitable opportunities elsewhere. In a booming economy like China's in the 2000s, there were plenty of fast-growing markets with foreseeable profits. Around 1998, for example, a cheap substitute to cellphones called Personal Handy-phone System (PHS) technology had explosive growth in lower-tier Chinese cities. PHS was an outdated Japanese wireless technology that carries only voices and are only implemented in short distances. Yet, because the PHS technology was cheap to deploy, low cost to use, and easy to entry, it attracted investment from major Chinese telecom equipment manufacturers. But PHS is a dead-end for innovators: the technology is close to its end of the product life cycle; too many entries lock the Chinese manufacturers into price competition; and because the technology has no potential to evolve, there are not much technological capabilities which can be built on PHS to move to higher value-added products and markets. UT-Starcomm, a

startup that specialized in PHS and which had grown into an enterprise worth hundreds of millions of dollars, had never succeeded in anything outside of PHS (Interview 49).

Thus, Huawei's choice of developing WCDMA technologies was part of a strategy to invest in R&D capabilities and knowledge base to seek long-term returns. Investing in the WCDMA technology meant head-to-head competition with multinational giants such as Ericsson and Alcatel-Lucent in an unproven market. Aside from betting on a potentially larger market, Huawei engineers acknowledged that R&D on the pathway of WCDMA requires steeper technological learning. A key technology capability critical to developing communication technologies that Huawei accumulated over the years was to master software algorithms. Modern telecom devices are essentially systems to process and transmit digital signals, and at the core of the system are algorithms for digital processing. Mastering algorithms is critical to implementing telecom protocols and designing efficient circuits and integrated chips, which all contribute to efficient designs of telecom devices. Implementing algorithms to efficient designs are often skills that are learned over time, requiring long-term accumulation of capabilities. It takes eight to ten years for Huawei to train one skilled engineer (Interview 49). But these deeper capabilities not only are the critical components for technological innovation, but also allow Huawei to be less restricted by technical barriers from competing in technological standards.

Huawei's entry into the Chinese TD-SCDMA market illustrates how such capabilities allow the company to be more flexible in moving between technology and markets. Huawei did not make substantive investments in TD-SCDMA until 2006 when it became clear that the TD standard would be deployed. In the first few rounds of procurements by China Mobile (the government-designated operator to deploy TD-SCDMA network), Huawei was lagging its domestic competitors. By transferring expertise from WCDMA to TD-SCDMA, Huawei quickly

took over as the market leader in 2011. It should be noted that in this case, the Chinese government organized a TD-SCDMA Industrial Alliance (TDIA) to include domestic manufacturers where members share a patent pool of TD-related patents. The state-owned Datang, which developed the TD standards, thus was not able to exclude Huawei from the market-using patents.

#### *5.4.3 Investment in A Capable Workforce*

Solving user's problems and accumulating basic R&D capabilities can potentially pose conflicting demands for a business organization and drag the R&D efforts in different directions. During my visits to Huawei, I have been exposed to contradicting views of the role of R&D within Huawei's organization. On the one hand, Huawei executives almost always dismiss the notion of a central role of R&D in Huawei's strategy, but instead, stress that Huawei organizes its activities including R&D following the company's "customer centered" mission (Interview 43, 47). On the other hand, executives with a career started in R&D (which accounts for the majority of Huawei executives) admit that Huawei is very patient in long-term investment in technology, citing examples of various learning and experimenting opportunities during their careers (Interview 48, 49, 50, 51). How does Huawei manage to meet these conflicting goals? Huawei's approach, I argue, is to invest in a motivated and flexible workforce through widely distributing the gains from its success.

Huawei engineers are known for being highly motivated, willing to work for long hours in poor conditions. Since its early days Huawei had developed mechanisms to mobilize a large number of engineers to concentrate on achieving goals in a compressed time frame. Such practice is internally called "*Yaqiang Yuanze*" (压强原则, or "Pascal's law" as in physics), a metaphor

from the story of Pascal's barrel in which water was filled in a long vertical tube to achieve hydrostatic pressure so large that it can cause the barrel below the tube to burst.

An example from Huawei's internal journal "Huawei Ren (or, Huawei People)"<sup>22</sup> illustrates how Huawei's routines combined with a sense of the market and knowledge base could contribute to reduced time to market. At the end of 1999, Huawei learnt that China Telecom intended to build CDMA networks, but Huawei did not have CDMA product offering nor did Huawei had sufficient accumulations in key technical standards<sup>23</sup>. Yet Huawei executives decided to seize the opportunity, and they quickly assembled a development team of 80 engineers from five main divisions (wireless, digital communication, optical network, fixed network) with all sorts of expertise in software, hardware, testing, quality control, etc. The team was sent to a resort in suburban Shenzhen to make a breakthrough in developing CDMA switches and HLR products in a short time. Tang described the process: "the team read (the CDMA standards and protocols) during the days, and discussed and debates at nights", "we leveraged the expertise in GSM, to rebuild modules and processes (of CDMA)", and "product manager invited a CDMA expert from Chinese Academy of Science to answer questions for us". The description was quite similar to an intense science camp, perhaps, with very lively and dynamic learning going on. As a result, it took only 50 days from dispatching the team to the resort to successfully connecting a call on their prototype!

What kinds of incentive mechanism and cultural norms has Huawei developed to enable the mobilization of its engineers? At the start-up stage, Huawei appears to have mainly attracted

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<sup>22</sup> Tang Xinhong, "CDMA, days and nights at Shiyuan Lake", Huawei Ren, issue 258, 2014/10/11.

<sup>23</sup> Huawei officially claimed that the company started R&D on CDMA and related technologies in 1995, and during 1996-1998, Huawei received a grant from the National 863 Program to develop "CDMA WLL system" with the result of a successful CDMA prototype ("Huawei's road to CDMA", *Huawei Ren*, issue 122, 2001/20/26). It is not uncommon, though, for a private company like Huawei to exaggerate its qualifications in order to secure contracts with the government and state-owned carriers.



two types of employees: engineers who gave up or lost secure jobs in the state sector in the late 1980s, and researchers and students from research institutes and universities with which Huawei collaborated on product development. In the latter category, graduates from Huazhong University of Science and Technology (HUST) and South East University (SEU) had been a primary source of talent. These early cohorts of Huawei employees were either betting on Huawei's growth opportunities or being attracted by Huawei's R&D culture. Thus, by selection, Huawei employees were highly motivated (Interview 50).

It was probably the establishment of employee stock ownership plan (ESOP) that provided an enduring basis for employee motivation and organizational integration at Huawei. Huawei's employee ownership was born out of financial necessity at the cash-constrained start-up stage. In 1992, Ren established Huawei as an employee-owned company by diluting his own shares. Following the local regulation in Guangdong province, the majority of Huawei's shares are held by two internal labor unions, while Ren holds only 1.4% of the shares. Employee ownership partially relieved Huawei's capital constraints, as individual employees might choose to contribute all their bonuses, which could account for as much as 50% of their total incomes from Huawei to be invested in the company. Perhaps more importantly, by giving employees a stake in the company, employee ownership gave Huawei a means to retain and motive its workforce, even those Huawei employees were considerably worse off than their peers in Shenzhen in wealth accumulation in early- and mid-1990s because of contributing to the ESOP. Nevertheless, those who stayed with Huawei were handsomely rewarded: the value of the internal employee shares (often called phantom shares) is tied to the net assets of Huawei, which experienced explosive growth in the late 1990s (Interview 40).

As the founder of a company that would be among the Fortune 500 in the United States, Ren is only modestly rich among China's most successful businessmen. By choice, Huawei is not listed on a stock market. In contrast, founders of younger Chinese high-tech companies that are much smaller in scale and have lower profitability often become among the richest people in China when the companies do an IPO. In this regard, Huawei has distributed its wealth more widely among its employees, the group of people who created that wealth. Over the years, Huawei has made various adjustments in the distribution of shares under the ESOP to, for example, include overseas employees in a similarly structured ESOP program and to seek a balance between rewarding senior employees for their past contributions and motivating the efforts of junior employees.

Huawei currently has no plan to list on the stock market, despite the fact that a stock-market listing would make those executives who have accumulated the most shares very rich (since, given Huawei's achievements, there would undoubtedly be a speculative bidding up of its stock price), and it would enable the current generation of retirees to cash in their shares by stock-market sales rather than from Huawei's own cash flow. By remaining private, however, Huawei's Board of Directors and the company's human resource function retain full control over ESOP's incentive mechanism. They also avoid the inevitable demands by outsiders who might accumulate substantial stock to "return value to shareholders" even though these public shareholders would not be the ones who had contributed to creating that value in the first place. Huawei executives firmly believe that meeting such value-extracting demands from the outsiders will sacrifice the long-term interest of Huawei (Interview 43).

In addition to the ESOP, Huawei's career structure derived significant characteristics from the early experience of the company's product development and market entry strategies. There are

two main routes by which a fresh recruit to Huawei can climb up the corporate ladder. One route is the R&D engineer route, exemplified by the fact that currently the majority of the Executive Management Team (EMT) members had experience in R&D projects. The early success of Huawei was crucially linked to the development of the large-scale switch (C&C08), and hence it would make sense that team leaders in the project would have substantial influence in the further development of the company. A prime example is a young junior engineer, Li Yinan, who proposed the key ideas of optical fiber connection and distributed module designs in the development of C&C08, and subsequently moved up to the level of corporate executive. The other route is by becoming a “frontline” engineer or sales manager who is willing to be dispatched to localities where conditions are poorest, but compensations and prospects for promotion are also the best. This route is also shaped by Huawei’s success in building the company through contracts in rural China and developing countries.

Huawei’s corporate culture has been shaped by the emphasis on R&D and market access in a similar way. In the early days of working with rural and far-off network operators, Huawei’s “frontline” engineers working on-site with the operators gained unusual autonomy, allowing them to make technical modifications on-site and to initiate problem solving with R&D engineers back at headquarters (Feng 2010). Such an arrangement evolved out of the necessity to ensure faster responses to customer needs, thus outcompeting the slower responses of MNCs/JVs with their centralized decision-making by headquarters in major coastal cities or overseas. Huawei’s system has nurtured a culture of empowering lower-tier employees, providing ample opportunities for young engineers and salesmen to take on major projects at early stages of their careers.

As the size of Huawei’s workforce expanded dramatically over the 1990s, from less than 600 employees in 1990 to grow to 6,000 employees in 1997 and 12,000 in 1999 (Interview 50, 51,

52), its human resource strategy shifted from attracting experienced people with domain expertise to training fresh university graduates. Like most Chinese industrial companies, Huawei has a system of apprenticeship, in which one experienced employee works with two or three new recruits to teach them the company procedures. But perhaps because of the relatively high rate of turnover that has resulted from Huawei's fast-paced, high-stress working environment (as well as abundant outside opportunities in China's high-growth economy), since the mid-1990s Huawei had been conscious about establishing routines, codifying knowledge, and actively managing organizational memory so that its operations are not dependent on specific persons. This emphasis on embedded organizational learning helps to explain Huawei's willingness (or perhaps Ren's insistence) on recruiting IBM consultants to implement the Integrated Product Development (IPD) framework that routinized the processes for decision-making, cross departmental and functional interactions, standardization of work flows, and internal reviews.

## **5.5 Innovative Firm and Innovation Pathways**

In this chapter, I document how Huawei, a private telecom equipment manufacturer, grew and approached the forefronts of innovation through a series of technological innovations: The C&C08 digital switch, distributed base station, and SingleRAN wireless technology. These innovations have important commonalities, that is, they can all be described as architectural and disruptive innovations. By architectural innovation, I mean Huawei's switches and base stations improve through altering the underlying ways of putting components without completely changing basic functionalities. Huawei altered the designs of telecom equipment by being an early adopter of using more software to realize switch functionalities (or, so-called soft switch). Except for the latest SingleRAN technology, Huawei's earlier innovations did not create or define new markets.

Nevertheless, soft switch technologies are disruptive because such technologies were initially cheaper and inferior, only evolving to become more capable later. The nature of the technology thus shaped Huawei's growth trajectory to move from low-end to high-end markets.

Huawei's innovation success, however, should not be simply attributed to the disruptive trajectory of the soft switch technologies. These technical and market successes are outcomes of Huawei's model of innovation, which I summarized as: integrating user knowledge in the innovation process, investing in long-term accumulation of technology and capabilities that transferred across technology standards and markets, and maintaining an extremely motivated and flexible workforce through widely distributing gains from the company's success. Such model works well for Huawei, because it transforms a strategy of high-cost R&D investment into competitive advantages. In this way, Huawei can adapt to changing technology and evolving Chinese industrial policy, leapfrog incumbent multinational corporations from neglected markets, and take advantage of China's large supply of raw engineering talent.

What does the case of Huawei tell about the growth of innovative firms in China?

First, the case of Huawei highlights the role of formal R&D, especially product design activities at a firm's early stage of development, is important even in an emerging economy. Previous studies of East Asian economies and companies had advocated a learning pathway, in which companies start from simple assembly and manufacturing activities and move gradually to sophisticated design and R&D through learning and imitation (Hobday 1995; Kim 1997). Because Huawei started from selling cheaper switches, observers from outside have perceived the company as following such a pathway of from imitation to innovation (Fan 2006; Fan & Gao 2016). However, this study shows that Huawei's early engagement in R&D activities created a different pathway in which an emerging economy company could compete on product innovations from

early on. Manufacturing is no longer a necessary step towards higher-level capabilities such as design and R&D. As the experience of failed Sino-foreign joint ventures shows, over emphasis on manufacturing and imitation might not result in the accumulation of necessary technical knowledge and development experience, leading to stagnation in an industry with rapid technological changes.

Huawei's case illustrates a changed world since the 1990s, in which product innovation is a viable pathway for emerging economy companies to succeed. The proliferation of the global supply chain and the dominance of a small number of contract manufacturers reduce the advantages of efficient manufacturing, but place a premium on product innovations. Today Huawei keeps the manufacturing of only the very high-end and security-concerned gears in house, while outsourcing to OEMs such as Foxconn for its mainstream products. It is a business model not significantly different from leading multinationals such as Apple or Cisco. The implication is that any newcomers following the steps of Apple or Huawei would have to compete in designing products with the newest technology, regardless of whether it is from a developed or developing economy.

Second, Huawei's experience shows that building large-scale organization with skill retention is an effective strategy in the Chinese environment. Compared to contemporary Western companies specializing in the design, R&D and marketing parts of the value chain, Huawei scaled up more quickly through hiring more people and diversifying into a number of markets and technologies. The tendency to grow large for Chinese firms is often simply put as a way to add more manpower and take advantages of relatively low labor costs (Zeng & Williams 2007; Fuller 2016). However, companies that are simply large without effective skill retention might not have sufficient incentives to invest in employees' human capital, given the weak intellectual property

protection environment, and thus they have little chance to develop superior employee skills and organizational capabilities. On the other hand, through an employee ownership scheme and structured career ladders, Huawei is able to ramp up R&D, train employees, and make long-term investment in organizational capabilities, while the company can still effectively retain skills, protect IPs, and profit from innovations. Note that there is a striking similarity between Huawei and Japanese companies in the 1970s and 1980s which emphasized skill retention to build superior organizational capabilities (Johnson 1982; Lazonick 2005). A key difference between Huawei and the Japanese companies in their retention strategy, though, is the difference between Huawei's employee ownership scheme and the life-long employment in Japan. Compared to the Japanese-style life-long employment emphasizing loyalty and commitment (Lazonick 2005), Huawei's employee ownership scheme is organized around sharing the growth of the company: it requires its employees to make investment in the company and the company then shares gains from innovation and productivity growth with its employee owners. In this sense, the Huawei system of employee retention is more transactional and less relational than the Japanese companies, as the gains and losses from the employee ownership can be clearly calculated from accounting sheets.

Finally, Huawei's experience highlights the importance of independent strategy and management while maintaining relationships with the Chinese state. The role of the Chinese government in industrial promotion has always been controversial. In the telecommunication technology, the Chinese industrial policies, both in the forms of "Trade Market for Technology" and the indigenous standard setting, were proven to be opportunistic, intending to create shortcuts for Chinese firms but did not lead to the most effective path for long-term technological accumulation. The Chinese industry policy maker did not pay enough attention to the most critical window of opportunity in the telecom equipment industry - an architectural change via using soft

switch technologies. Part of the reason is that the vision of the policy makers had been hijacked by the less competent state-owned enterprises, especially Datang, the developer of TD-SCDMA. Datang bet on its specialty, the “Smart Antenna” technology, in compiling the TD standard. Yet, “Smart Antenna” was not a technology sophisticated enough to give Datang or other Chinese firms strong competitive advantages.

In this case, independent strategy and management allowed Huawei to pursue a difficult technological trajectory but one that yielded the best long-term outcome. Huawei maintained its autonomy, partly due to its private ownership and thus peripheral status in the political economy system until at least the 2000s. Even Huawei might have already had stronger technical expertise and larger scale than the state-owned Datang in early 2000s, when the latter had an oversized voice in industrial policy making. Without the ability to influence policy, autonomy was important for exercising strategic control over the company’s technological directions

It should be noted that Huawei was not punished or excluded from the domestic market for not fully committing to national policy goals. It can be seen as both a strength (for flexibility) and a weakness (for lacking coercive power) of the Chinese industrial policy.

Huawei’s system of innovation is not without flaws. While Huawei has shared the gains from innovation and growth among its employees, its organizational foundation of such sharing, the employee stock ownership program, is restricted to mostly college graduates recruited for professional jobs. There are some 10,000 Huawei production workers and 7,000 temporary workers are not eligible to participate in the employee ownership program, not to mention the hundreds of thousands of low-skilled workers working for Huawei’s contract manufacturers, such as Foxconn, who work at low wages and in harsh working conditions. Like any other lead



multinational companies in the global value chains, Huawei benefits from this regime of exploitative labor relations rather than seeking to transform it.

As Chinese society gets richer and Huawei becomes more internationalized, there is a growing challenge for Huawei to maintain a vigorous workforce. The ESOP system stresses material and financial benefits, which might become less appealing to the younger generation who grew up in affluent urban families. To attract, motivate, and retain talent under its high-stress work environment, Huawei has been experimenting with new programs such as Huawei Fellow, a program that gives prestige to the most talented Huawei scientists and engineers and allows them to participate in the leading international scientific community. However, these incentives apply only to a small group of elite engineers; thus it is not clear how Huawei would keep motivating its ordinary employees through material and non-material incentives.

As one of the most innovative firms in China, Huawei itself is an idiosyncratic case as the firm's unique capabilities are its sources of competitive advantage. That having been said, there are four general lessons that can be learnt from the trajectory of Huawei about the development of innovation capabilities in China.

First, the synchronization of state, market, globalization forces for capability development is critical in early stages of developing a new industry. The emergence of Huawei and other competitive Chinese telephony switch makers in the 1980s and 1990s greatly benefited from such a synchronization, enabled by the interactions of policy with market and industry conditions. The Chinese government implemented three sets of policies. The first was to invest in telecommunication R&D and personal training. The engineering graduates from Chinese universities and a working prototype of digital switch diffused from public research institutes formed the basic capabilities of indigenous companies. The second was to invest in telecom

infrastructure throughout of the country. That expanded the parts of rural market more accessible to local companies and provided opportunities for their growth. The third was to build joint-venture firms with multinational companies to manufacture switches in China. Although it is debatable how much spillovers these joint ventures had created for the local industry (Shen 1999; Mu & Lee 2004), through the JV activities in China, the indigenous firms were exposed to the global supply chains and utilized that to access critical components, such as semiconductor chips, that China was not able to produce. The three sets of policies and interactions thus created the critical conditions for the new industry: basic capabilities, supporting industries, and market opportunities.

Second, as firms grow larger and accumulate more internal capabilities and resources, they become less dependent on the synchronization conditions. Huawei's later success in the wireless market illustrates this point. The indigenous TD-standard policy and its slow rollout process in the 2000s was a case of unsynchronized policy, as it both inhibited domestic market growth and reduced complementarity with the global supply chains. Huawei was less affected in the 3G markets, because the company used internally developed WCDMA capabilities and pursued foreign markets. Nevertheless, it is evident that synchronization remains important for smaller and less capable firms.

Third, the synchronization is more likely to be achieved through more inclusive innovation and industrial policies. By inclusive policy, I mean the policy that distributes benefits and opportunities broadly across the society without deliberately excluding certain players. An inclusive policy might be more likely to lead to synchronization because it includes more players, thus more entrepreneurial activities, in combining resources and exploit opportunities. Comparing to the telecom industrial policy in the 1980s and 1990s, the TD-standard-centered policy in the 2000s was less inclusive. The development of critical technology capabilities, the TD standards,

were carried out by a state-owned firm, Datang, while in the previous era, public research institutes developed and allowed the diffusion of critical technologies and prototypes. The market access policy was also more open in the 1980s and 1990s, allowing domestic companies to participate whether they were big or small/public or private. These critical differences allow massive entries in the 1980s and 90s to exploit opportunities while only a handful of big players succeeded in the 2000s.

Finally, while the Huawei model of innovation can be hard to replicate, there are lessons to be learnt for other firms and sectors in the Chinese economy. Employee ownership is critical to the success of Huawei, as it provides a framework to incentivize the company and employees to invest in human and physical capabilities to access market and develop technology. But other Chinese firms are unlikely to adopt such governance structures. Though employee ownership and collective ownership firms were popular in the 1980s and 1990s, most of these firms were privatized, typically through management buyout, over the last two decades. It has been argued that the decline of firms with collective ownership was due to the state's favor of state-owned and foreign invested firms at the expense of domestic firms (Huang 2008). That being said, Huawei still provides an excellent example for other Chinese firms to learn from. Aside from setting up employee ownership, firms can implement various arrangements to share profits from innovation and productivity growth with employees to encourage investment in firm-specific human capital. Huawei's other innovation strategies, especially the aggressive targeting of local markets and the development of market access capabilities, have been diffused across the economy.

## **CHAPTER 6. LESSONS FROM CHINA'S INNOVATION PATHWAYS**

### **6.1 Review of Findings**

Through case studies of leading Chinese firms in the telecom equipment industry and the semiconductor industry, I illustrate how innovation pathways occur in the Chinese context. An innovation pathway in this study is defined as the process of developing, accumulating, and combining of capabilities through which business firms may engage in frontier innovation activities. Considering the unique historical circumstance of Chinese development, i.e. being the world's most populous country, having a strong and growth-oriented government, and being part of a liberalized international economy with globalized production, I propose that innovation pathways in China occur most likely when state policy synchronizes with domestic market development and global industry evolution, that is, the resource, capabilities, and institutional framework provided by the government enable firms to combine and integrate market opportunities and complementary capabilities provided by domestic market and global industry for technological development.

In the case of the telecom equipment industry, Huawei and other indigenous firms found a synchronization of state, market, and globalization forces in their early growth. In the 1990s, Chinese public research institutes diffused the technologies and prototypes to develop large scale digital switches. Sustained by public spending on telecommunication infrastructure, the domestic market was not only expanding but also creating demands for locally adapted technologies. Globalization provided Chinese companies access to suppliers of key components, such as general-purpose computer chips, that China was unable to produce. Indigenous Chinese companies captured opportunities from this synchronization through building on the emerging though

rudimentary soft switch architecture, leveraging capabilities in the GPNs, and aggressively advancing in parts of the local markets they had intimate knowledge. The result was the emergence of competitive indigenous telecom equipment firms that were especially good at generating innovations to solve local problems in the late 1990s.

However, such synchronization disappeared when it comes to the emerging wireless telecom technology in the late 1990s. At the time, the Chinese mobile communication market is smaller and more homogenous than the fixed-line market, and the mobile infrastructure market had been reserved by multinationals and state firms. The government pushed for indigenous 3G wireless standards, intending to separate China from world market and protect local firms. Yet such policy was at odds with leading non-state firms Huawei and ZTE, which were already internationalizing and more interested in investing in one standard, WCDMA, that had the largest shares of the world market. Unsurprisingly, the asynchronous policy did little help for the leading non-state companies to accelerate innovation.

In this regard, Huawei is an idiosyncratic case in its becoming of the most innovative firm in China. Through strengthening internal R&D and investing a set of core capabilities such as algorithm development and IC design, Huawei inserted itself in a strong position in the global supply chains and avoided being trapped as a fast follower. Through transferring marketing, sales, and user engaging capabilities developed in China to the advanced European markets, Huawei not only avoided being trapped in reinforcing China-specific capabilities but gained access to a sophisticated user base with advanced knowledge in Europe. The development and transferring of capabilities is even more remarkable if considering the company was moving from fixed-line switch to wireless communication businesses. Huawei's innovation success should be attributed

partly to its success of developing and retaining skills internally and partly to the company's early internationalization strategy, allowing it to be less dependent on synchronization at home.

In the semiconductor industry, the constant struggle of Chinese firms to closing technological gaps with international leaders illustrates how hard it is to search for synchronization. The semiconductor industry emerged as a state industry with legacies from the planned economy era, and throughout the 1990s, the state was the driving force for industry and technology development. Huajing, a leading SOE in the 1980s and 90s, was more successful than other SOEs because Huajing was sensible to the local markets, producing low-end transistors to supply the booming consumer goods markets. However, the grasps to local markets were quickly lost as globalization allowed Chinese electronics manufacturers to use higher quality and cheaper semiconductors from imports.

The two statist pushes in the 1990s, Project 908 and Project 909, were both unsuccessful in generating anticipated results, i.e. closing the technology gap between Chinese firms and international leaders. Despite severe corporate governance and management issues haunting SOEs, the state policy failed to synchronize with the pace of global industry evolution and local market development. Under globalization, even the government cannot create a meaningful market under Chinese control with sufficient size and sophistication to support local firms. The government's decision to leave little strategic autonomy at enterprise level only worsened the subordinate position of Chinese firms in participating in MNC's supply chains.

In the 2000s, a tacit alliance between CCP leadership and the international entrepreneurial class led to rapid growth of newly established Chinese foundries. The foundry's export-driven business model supported by subsidies from local governments brought in both commercial

successes and technological catch-up. Yet, without the support of a local market, the pace of growth proved to be unsustainable and highly subjective to fluctuations in the international market.

A synchronization only emerged recently. The leading Chinese foundry SMIC now occupies a strategic position at the intersection of local economic development and global production. SMIC continues to function as a node in the GPNs, allowing knowledge follows through the subcontracting relations. But SMIC is also reaping benefits from a local industrial ecosystem it helped to create: in the booming local electronics markets, Chinese IC design houses and system companies seek advantages from producing at local foundries. A lack of committed capital and publicly-funded R&D, which have been prolonged weakness in the industry, are finally being addressed by government sponsored investment funds and R&D consortia. Although it is too early to tell whether such synchronization would lead Chinese companies to the desired result of technological leadership, there are positive signs: SMIC in 2016 has one of most healthy margins in the industry, and the progress of further investment and technological development has accelerated.

## **6.2 Innovation Pathways: From Sectoral Process to National Pattern**

Innovation demands a broad range of capabilities, from product design and R&D to manufacturing and scale-up to sales and distribution, as well as the integration of these skills and capabilities in technology development and commercialization. The development and accumulation of such capabilities in a firm, a region, or a nation are supported by a set of institutions and practices that would characterize its innovation pathways.

Since the second Industrial Revolution, the vertically-integrated business enterprise as an institution had a prominent role in industrial development and innovation, precisely because

vertically-integrated firms are capable of cultivating and bringing together the full range of capabilities required for innovation. The vertically-integrated firms possessed three advantages over the smaller, specialized firms in this regard: first, they have the financial muscles to make the physical and human capital investments in establishing a variety of types of capabilities required for bringing a product from idea to market; second, they have the management skills to coordinate capabilities residing at different types of business functions, and establish critical linkages between them in the learning and innovation process; third, they have developed sophisticated organizational arrangements to retain skilled employees so that these firms can accumulate capabilities over the long term (Chandler 1977; Lazonick 2009).

In the late 19<sup>th</sup> century, large vertically-integrated enterprises in the United States and Germany pioneered in commercializing mass-production technologies, allowing the two countries to overtake the Britain in industrial leaderships (Chandler and Hikino 1997; Lazonick 1991). After World War II, the later generations of industrializers also relied on vertically-integrated conglomerates for industrialization and catch-up development. In Japan and Korea, industrial conglomerates in the forms of *keiretsu* and *chaebol*, respectively, spearheaded in establishing advanced technology capabilities and moving their countries from low-skilled manufacturing to high-value-added and innovative activities in various advanced industries (Johnson 1982; Amsden 1989). The development of vertically-integrated enterprises and the process of capability accumulation are supported and embedded in national institutions. In the heyday of Japanese development, for example, the development process is supported by a set of arrangements, including cross-shareholding by firms within a *keiretsu*, life-long employment for skill retentions, and a main bank system to finance investment in innovation (Lazonick 2005).



In this study, I examined Chinese firms in two of the most knowledge-intensive steps and activities in the ICT industry supply chains: R&D of ICT systems and semiconductor design & fabrication. I found that the most successful Chinese firms in these sub segments, Huawei and SMIC, respectively, did not emerge as the vertically-integrated conglomerates as firms in the US, Japan, Korea and other the previous industrializing economies did. Neither Huawei, SMIC, or other Chinese firms possess the full range of capabilities in house to bring a product from idea to market. This does not prevent them from becoming technological leaders at home and abroad. Because Chinese companies have become innovative by specializing in a narrower set of core capabilities while relying partners in the global production networks to access a broad range of complementary inputs and capabilities, Chinese firms from different sub segments pursue different innovation strategies and pathways to develop their capabilities rather than following the same templates or models. In another word, there is a variety of pathways to innovation in the Chinese economy.

Emerging from the study of the two industries are three innovation pathways that Chinese firms have explored:

The first is an innovation pathway shared by Huawei and other successful non-state firms, which I call an “indigenous innovation” pathway. Firms succeeded through this innovation pathway tend to be downstream system integrators that are close to the end market and emphasize on product innovation. Firms following this pathway typically start by forming a set of core engineering capabilities from basic resources in the Chinese economy, such as engineering skills, market knowledge, and rudimentary technologies. They utilize their intimate knowledge of the local markets to access underserved demands, and leverage complementary productive capabilities from the global production networks, to bring ideas to market. Revenues generated from the large

domestic markets enable these firms to initiate the process of capability accumulation. By learning from accessing local markets, these firms develop marketing, distribution, and customer-engaging capabilities. By reinvesting profits into further development, these firms have a chance to deepen and broaden its core capabilities through investing in R&D, building complementary capabilities in house, and diversifying into related technologies and markets. As the Huawei case suggests, the level of innovation success, i.e. closeness to frontier innovation, depends on S&T and financial resource provided by the state, the institutional framework for firms with non-state governance structure to operate, and the firm's willingness and ability to invest in capability development. To facilitate the emergence of the "indigenous innovation" pathway, a synchronizing government policy should provide firms with capabilities, such as through public funded research and human resource training, to exploit market opportunities, and negotiate with multinational corporations through trade and competition policies to secure better terms for domestic companies to tap into inputs in the global supply chains.

A second innovation pathway is through complementing export-oriented firms with forward linkages to the domestic markets and backward linkages to the national R&D and industrial infrastructure. This innovation pathway might be called a "Grounded Globalization" pathway. It is illustrated in the SMIC case, but it is also widely applicable to various types of export-oriented firms and international entrepreneurial firms. These firms have their initial core capabilities originated from the global production system, such as subcontractors of multinational corporations or start-ups by international entrepreneurs bringing in technology developed elsewhere. The initial core capability is often narrowly focused in the form of specialization in one or more steps or stages of production to fit in the supply chains. To advance towards innovation at technology frontiers, these firms need to broaden their capabilities in beyond a narrow set of

activities. They need to develop their own capabilities to access markets, instead of relying solely on coordination by MNCs, to respond to market changes more effectively and to define new markets; they also need to link to the national R&D infrastructure to broaden sources of technology and learning. To accelerate this “Grounded Globalization” innovation pathway, government policy needs to facilitate linkages between those internationalized firms with the broad domestic sectors, supply resources inaccessible in the global production system, such as long-term risky finance, and provide institutional supports for governance structure in the internationalized firms.

A third innovation pathway is through absorbing and improving on imported foreign technologies to build up the various types of capabilities necessary for innovation. This is the innovation pathway envisioned by Chinese policymakers in their “Trade Market for Technology” policy and strategy. As I have showed, the TMFT policy has achieved limited successes in the two sectors in this study. Experience of the two industries shows that, for the policy to work, it demands enormous state capacity. For the TMFT policy to succeed in any industry, the state has to negotiate with advanced foreign firms in securing favorable terms of technology transfers, set up proper governance and incentive structures for domestic firms to engage in technology importation and learning, strengthen the ability of domestic firms to absorb technologies – the absorptive capacity – through public funded research and human resource training, and regulate markets to ensure the domestic firms to be profitable and under competitive pressure for upgrading. In both cases in this study, branches of the Chinese government did not show such a level of coordination and regulation capacity. Nevertheless, the innovation pathway through technology transfers might still be a valid process under specific conditions, as evidenced in the high-speed rail industry, where national central planning and a captivated market controlled by government procurement have made such pathway possible (Liu, Lv and Huang 2016).

The variety of innovation pathways in the Chinese economy is, nevertheless, embedded in the Chinese institutions:

First and foremost, the origins of capability in both telecom equipment and semiconductor industry are linked to public funded research in the past. In the case of the telecom equipment industry, the emergence of a group of indigenous firms, including Huawei, ZTE, Datang, and Great Dragon Telecom, in the early 1990s was a direct result from public funded research on communication technologies and the development of prototype switches in public research institutes. In Huawei's early R&D efforts, the company was able to tap into pools of technical expertise in Chinese universities and public research institutes through consulting contracts or poaching key scientists and engineers. In the case of the semiconductor industry, China invested in semiconductor research and education early in the 1960s, but the early public funded research did not translate into industrial competitiveness. The failure is partially because of the lagging of Chinese research and partially because of restrictions on entry of non-state firms until the end of the 1990s. Nonetheless, because of China's emphasis on science and engineering in public funded research and education in earlier period, Chinese technocrats in key posts of making semiconductor industry policies in the 1990s, including President Jiang Zemin, Minister Hu Qili, Jiang Shangzhou, among others, had technical backgrounds, overseas experience, and ties to the international technology community. The backgrounds of the key technocrats might have explained why the government opted for a strategy to sponsor semiconductor firms with international entrepreneurship (exemplified by SMIC) rather than domestic private firms.

Second, the finance of industrial activities is heavily influenced by the political institutions, especially central-local relations. Economic decentralization gives Chinese local governments enormous capacity to fund industries, but the local governments favor infrastructure and

manufacturing more than advanced R&D because the former creates jobs and growth quickly. Tapping into the Chinese system of industrial finance for funding innovation activities, thus, is not straightforward. In the semiconductor industry, the foundries rolled on local government subsidies for rapid expansions of manufacturing capacity, but relied almost exclusively on the central government for R&D assistance. In the telecom equipment industry, Huawei relied on internal finance to establish innovation capabilities. But Huawei and other indigenous firms benefited from local spending on telecom infrastructure in the 1990s to generate enough revenues to sustain reinvestment and accumulation.

Finally, the accumulation of capability through retention of skilled employee is influenced by regional contexts. In the telecom equipment industry, Huawei developed effective organizational structures to retain skills through employee ownership, establishing deep capabilities over the long run. The regional context is that during Huawei's growth in the 1990s, Shenzhen and the surrounding Pearl River Delta region was primarily a manufacturing location, employing millions of migrant workers for assembly and manufacturing work. Huawei competed with ZTE, its main domestic competitor also from Shenzhen, and foreign-invested firms for skills. The result is that Huawei developed a relatively closed corporate system for skill retention. In contrast, when the semiconductor foundries were established in Shanghai in the 2000s, the returnee technologists had a vision of creating a Silicon-Valley-style innovation eco-system, building the foundry to support a large number of fabless semiconductor startups. SMIC employed an American-style employee stock option plans to attract and retain skilled managers and engineers, but many of its founding members later left to start their own businesses. Richard Chang, the founder, for example, later started a silicon wafer manufacturer to supply SMIC and other domestic foundries. By the early 2010s, Shanghai and surrounding areas already have a vibrant

semiconductor startup eco-system, with a few foundries supplying manufacturing capacity, a vast number of fabless design houses, and a set of government and non-government organizations facilitating collaborations between firms in the supply chain. The linkages and mobility between industries and local universities have also strengthened: technologists from semiconductor firms frequently teach at local universities and some of them have even become university professors (Interview 15, 23).

While the variety of innovation pathways can be traced back to Chinese institutions, there are questions about how sustainable these innovation pathways are. I found a strong evidence supporting the sustainability of the two innovation pathways identified in this study, the “Indigenous Innovation” pathway and the “Grounded Globalization” pathway, as both are widely utilized as templates for innovation and entrepreneurship in China. The “Indigenous Innovation” pathway is most recently exemplified by the trajectory of Chinese smartphone manufacturers. Firms such as Xiaomi, OPPO, and VIVO, excel in establishing brands, designing for the local markets, and building massive distribution networks online and offline, while relying on partners in the global production network to supply key componentry and manufacturing capabilities. Over time, the smartphone makers broaden their core capabilities to include software development and the R&D of key components. A startup ecosystem emerging from Shenzhen in the 2010s also adopts the “Indigenous Innovation” template. The start-ups in Shenzhen, with both domestic or foreign origins, take advantages of the established supplier networks in the Pearl River Delta region for rapid prototyping and manufacturing scale-up, and they have been able to bring product ideas to market through specialization in design and R&D and collaboration with the supplier network (Interviews).

The “Grounded Globalization” pathway pioneered by SMIC has become a template for establishing knowledge-intensive, high-entry-barrier industries. For example, when the Chinese government decided to sponsor a new domestic memory chip manufacturer to break into this capital- and knowledge-intensive industry and master advanced DRAM technology, it created Yangtze River Storage Technology, a firm with state capital but managed by ex-SMIC executives and Taiwanese technologists in 2015 (Yoshida 2017). A similar template has been applied for commercializing emerging technologies. Over the last decade, the Chinese governments and universities have been inviting foreign universities to establish joint research centers with local universities. Many of these joint centers have an explicit emphasis on technology commercialization, such as the XING Center at Tsinghua University in Beijing and the research centers of Hong Kong universities in Shenzhen. The idea behind these centers is to connect the emerging technologies with the vast market and industrial base in China for maximizing the chances of innovation success (Youtie et al 2017; Interview 53).

### **6.3 Contribution and Limitation of This Study**

The main contribution of this study to innovation theory and policy is a new view on how firms from China, the world’s largest emerging economy, can develop innovation capabilities.

Literature on technological innovation has drawn distinctions between different types of innovation activities by classifying into two broad categories of product and process innovation. In general, product innovation describes changes in concepts and technologies, usually being related to innovation capabilities in R&D and design activities. Innovation capabilities in manufacturing activities are related to process innovation as changes and improvement in manufacturing process and the method of product delivery. Within product innovation, scholars

pay attention to the differences in radical and incremental innovation, with the former introducing new concepts and technologies significantly departure from the past, and the latter making gradual improvement over existing ones. It is often assumed, at least implicitly, there is a hieratical order in skill requirements in different innovation activities, as radical innovation being most difficult, followed by incremental innovations, and process innovation being easiest.

Such conceptualization of innovation and innovation capabilities has greatly influenced how theorists and policymakers approach innovation and development in at least two important ways. First, since successful product innovation at technology frontiers is the most difficult, requiring a full range of highly complementary capabilities in R&D, design, and manufacturing, product innovations have been regarded as reservoirs for firms from advanced economies with the highest levels of capabilities. Even as globalization has delinked R&D and manufacturing geographically and organizationally in recent decades, it has been assumed that only the advanced economy firms can effectively access and combine capabilities in the global supply chain. Therefore, secondly, the concept of a hierarchical order of skills directly shaped the way we see how firms can learn. The accumulation of innovation capabilities by firms from industrializing economies is conceptualized as following a sequence of learning, mastering lowest skills in manufacturing first, and subsequently climbing up the technological ladders to develop higher-level skill sets in design, marketing, and R&D. Such a learning sequence is often conceptualized as a reversed product cycle, a process through which follower firms imitate and learn from industry leaders step by step.

There are, of course, competing views on this subject. One challenger is the “leapfrogging” view that see latecomer firms could capitalize on innovation breakthroughs to skip the learning sequences and develop a full set of skills and capabilities simultaneously (Lu 2000). Unfortunately,



the chances for firms from less developed economies to leapfrog are usually low. More recently, a “specialization” view sees that because of globalization and fragmented production, firms no longer need to develop the full set of skills but can rely on collaborations with partner firms in the global supply chain. In the case of emerging economies, firms are better off by specializing in manufacturing (Nahm & Steinfeld 2014). The specialization view, however, would not be able to explain the enduring successes of large innovative firms with all-around capabilities in driving the growth of wealth and technologies in advanced economies. And there is no reason for policy makers and industry managers from less developed economy not to desire such successes.

In this study, I present a different view on how firms from less developed economies can learn and how various types of capabilities can be accumulated and combined for innovation. The experience of the Chinese companies shows that there is more than one way to learn to innovate in today’s emerging economies. Neither do firms have to follow a learning sequence of reversed product cycle, progressing from manufacturing to R&D, nor should firms be stuck at lower value-added activities of manufacturing and assembly. Instead, innovative firms of emerging economies can start from a narrower set of core skills, leverage complementary capabilities in the national economy and/or in the global industry, and combine internal and external capabilities to bring ideas to market rapidly. Over time, the innovative firm can extend further controls on external capabilities through either developing in-house capabilities or supporting partners to develop unique capabilities to escape commodification. Not all companies will succeed in this process: many will fail to expand or upgrade core competence and continue to rely on external sources to access key technologies and capabilities, subjecting themselves to depressing margins from competition and making them vulnerable to changes in technology and marketplaces. Only a

selected few will achieve the status of frontier innovator with a full range of capabilities by establishing a strong in-house learning and accumulation system.

From a national perspective, it should be expected not all firms will develop all-around capabilities. But as long as a sufficient number of firms have a strategy to develop capabilities in various parts of the value chain, a nation can have a chance to develop a full-range of innovation capabilities and nurture leading firms that can coordinate and combine the full set of capabilities for innovation.

The starting point of development, therefore, does not have to be limited to the manufacturing space, either. As this study shows, firms from emerging economies can derive advantages not just from cheap labor and land, but also from the insider knowledge of the market, institution, and culture of their own countries. Innovative firms can utilize their insider knowledge to build capabilities to access market (i.e. marketing, sales, and distribution capabilities) and/or the capabilities to develop products (i.e. design, engineering, and R&D capabilities) for the locals, and leverage that to access external resources, such as capital, key componentry, and services. There is also an underestimated advantage in committing to a strategy for technological development from early on, as shown in the case of Huawei as a company betting on product innovation since it was a startup. The innovation-centered strategy helps building effective organization and healthy corporate culture, and more importantly, prevents the company from being trapped in activities that might be highly profitable but unconstructive to innovation capability development.

There are policy and management implications from the new ways firms learn to innovate, or what I call innovation pathways. A primary approach to promote innovations in this study is to search for synchronization of state, market, and globalization forces, that is, each of the three forces

providing opportunities, resources, complementary capabilities in the process of developing innovation capabilities by local firms.

The opportunities, resources, and capabilities provided by the state, market, and globalization forces take many forms. For Chinese firms that target the domestic market and pursue the “Indigenous Innovation” pathway, the large and expanding domestic market offer most opportunities to profit from innovations. The local market opportunity is especially beneficial for indigenous innovators when the local conditions posit unique innovation challenges to solved by innovators with intimate local knowledge. As it is shown in the telecom equipment industry case study, the complexity in operating environments by local operators across a wide range of geographical conditions in China was the key barriers for foreign equipment manufacturers, but overcoming such challenges is equally the opportunity for local manufacturers to capture an initial market. To enable local firms to capture such opportunities, it requires investment in resources and capabilities, including a legal framework allowing non-state firms to operate and compete, S&T and human resources provided through investment in research institutes and higher education, financial resources provided by banks and local governments to telecom operators to invest in the infrastructure and sustain demands for local products, and advanced technology inputs that China was not able to produce but access to such capabilities can be enabled through a liberal trade policy.

For Chinese firms following “Grounded Globalization” pathway, the critical opportunity is through China’s integration with the world economy enabled by the governmental policies. The Chinese economic policy that promote exporting and foreign investment allows local firms to acquire capabilities through producing for MNCs as well as a global entrepreneurial class to start business in the country. The latter is a critical route for China to establish high-tech industries that requires technical and managerial capabilities exceeding the capacity of local firms. As the

semiconductor industry case study shows, the growth of the internationalized firms also requires complementary resources, capabilities, and institutional framework provided by the state and domestic institutions. Such complementary resources might include reforms in corporate governance allowing the internationalized firms to recruit and retain talents globally, a functioning local capital market or access to international capital market to meet investment requirements, and the development of linkages to broad domestic business sectors and S&T infrastructures.

To achieve synchronization, it requires broad coordination among government agencies and business sectors. Accordingly, the key drivers of synchronization include governmental policies and strategies, informal government-industry exchange, corporate leadership and strategy, and efforts to upgrade capabilities including labor market skills, Chinese talent recruitment from abroad, the development of higher education including professional-oriented university schools. These key drivers contribute to changes in synchronization modes, e.g. from synchronization to asynchronous relationships and vice versa. As it is demonstrated in both case studies, governmental policies broadly define the relationship between the government agencies, domestic firms, and the global industry. For example, under the Trade Market for Technology policy, the linkages between domestic and global industry was narrowly defined as joint-venture relationship between selected SOEs and multinational firms. Only abandoning the TMFT policy allows the more innovative non-state firms to establish linkages with the global supplier networks, or the emerge of internationalized firms bringing in technologies and talents from abroad. The shift in government policies and strategy thus drive changes in modes of synchronization. Yet policymakers still depend on business enterprises to identify and exploit opportunities, combine and utilize capabilities in the national economy and global supply chain, and transform technologies into commercial successes. As in both industry studies, the synchronization went

hand in hand with the emergence of strong business firms. Accordingly, the formal and informal government-industry exchange plays an important role in coordinating government policies and business strategies in achieving synchronizations. Case studies provide both positive and negative examples in this regard. As a positive example, the exchange between CCP leadership and the broad international business and technology community of the semiconductor industry in the late 1990s allowed a shift in policy from the aftermaths of Sino-foreign joint-venture projects to a strategy of backing internationalized foundry startups, which led to fast growth of the domestic industry in the next decade. As a negative example, the capturing of industry policy in the telecom equipment industry by a few SOEs in early 2000s resulted in a local standard policy that proved to be less beneficial to the broad domestic industry. Finally, the efforts to upgrade broad capabilities in both government and business sectors through education, training, and the attraction of talents from abroad increase the ability to design and implement effective governmental policies and business strategies, and facilitate government-industry exchanges, thus increase the chances of achieving synchronizations in general.

Because the detailed approach to search synchronization is contextual and subject to industrial and national conditions, as clearly shown in this study, it is impossible to write a blueprint of government policies and business strategies to suit every scenario. Nevertheless, the present studies imply that there are two broad approaches, a passive approach and an active approach, in the search of synchronizations.

In a passive approach, synchronization occurs as incidents in the process of economic development, and business firms sense and exploit the opportunities emerging at the conjunction of previous government and business actions. It usually happens when income growth forms demand for certain manufacturing goods with localized tastes, the global industry is matured

enough to have resource slacks to complement local capabilities, and the state provides human resource and market institutions for entrepreneurial firms to operate. This search for passive synchronizations relies on entrepreneurs to spot and exploit opportunities. The role of public policy is limited to promote competition and entrepreneurship.

In comparison, in an active approach, the government and business create conditions for the synchronization to occur. If the global industry cannot provide resources for development, firms with strong market accesses could actively invest in creating complementary manufacturing, engineering, and R&D capabilities that is scarce or unavailable in the global industry. If the domestic market is underdeveloped, firms with strong productive capabilities could actively support the creation of marketing, distribution, user engagement and other market access capabilities, either by itself or through partnering with distributors. The government can support these initiatives through identifying weak links in the supply chains and supporting entries of domestic firms, providing financial and technical assistance to leading firms to strengthen their core competences, and undertaking long-term, risky R&D projects underinvested by the business sectors.

The distinction of passive and active synchronization is useful because active industry policy or government actions does not necessarily translate into synchronization. In both industries featured in this study, the Chinese government has been seeking to actively manage the process of industrial development. Yet, these actions rarely led to synchronization. The only case of synchronization in the early period of the telecom equipment industry seems like to be a case of passive synchronization, as the dominant industry policy at that time was promoting Sino-foreign joint ventures, while the synchronization emerging from public funded research, competition and

open market policy, and local spending on telecom infrastructure was rather unintended consequences.

In general, it is easier to anticipate and manage synchronization in later stage of industrialization than in early stages. In early stage of industrialization, the business firms have limited capability, supply chains and domestic market are underdeveloped, and even the government does not necessarily have sufficient capacity to coordinate various actors to achieve synchronization. In later stages of industrialization, as both government and business sectors have accumulated experience in managing industrial development, they are more capable of identify bottlenecks in further capability building and formulating strategies to close the gap and achieve active synchronization. This correlation between stages of industrialization and the likelihood of synchronization policy is most easily understood in the case of the semiconductor industry. The government policy in the 1990s intended to establish all-around capabilities within state-owned/joint-venture industrial conglomerates, yet its implementation favored only production and neglected various other aspects of capability building. As the industry has established itself in the 2000s, policymakers today can identify its weakness in talents, R&D, and linkages to domestic markets, and put policies in place to achieve synchronization.

The concept of synchronization adds to the understanding of government-industry relationship in innovation and development among a range of similar concepts and theories, including public-private partnerships, strategic industrial policies, joined-up government, and industry-promoting administrative guidance (Link 2006; Ling 2002; Johnson 1982). Similar to the established concepts, the idea of synchronization emphasizes exchange and relationship between government and firms. But the synchronization concept adds in two important dimensions. The first is a dynamic dimension in terms of timing for the policy. Because the concept of

synchronization is developed in the context of building innovation-based industries with rapid technological and market changes, timing matters in designing and delivering effective policies. Policy makers intending to promote rapid-innovation-based industries, as the Chinese government did, need to monitor the progress of domestic development as well as global trend in order to tailor policies to strike at windows of opportunities. The second dimension is an international dimension. In previous eras, industry-promoting administrative guidance might take the global industry as relatively stable as sources of technology, markets for export, and models for business enterprises. Yet, no nation today can establish an innovation-based industry without exchanges of ideas, technologies, and talents with the rest of the world simply to keep up with the pace of global industry evolution. Taking the international dimension into consideration further enable dynamic and effective policy making.

In this study, the concept of synchronization is developed to address successes and failures in transforming Chinese industries into innovative producers, or what I call the unfolding of innovation pathways. Although I have shown that throughout all stages of industrialization, synchronization of state, market, and globalization forces facilitate the emergence of innovation pathways, the concept of synchronization has its most utility in managing later stages of industrialization. Here, I consider the applicability of synchronization concept in policy making in scenarios of industrializing and industrialized economies. In early stages of industrialization, while synchronization provides benefits through shaping the later development trajectory, it should not be anticipated through active policies considering limited capability within government and business. The concept of synchronization emphasize complementarity between various forces in domestic and global economy, but itself provides limited tools for jump starting industrialization. Synchronization has little applicability in industries or economies that have already achieved the



status of innovation leaders whose challenges are mainly in maintaining innovativeness and anticipating challenges. Thus, the concept of synchronization is most useful in middle- to high-income economies in the process of establishing a full range of capabilities for innovation. To achieve synchronization, the main task of policymakers and business strategists is to identify gaps in capability offered in the national economy, exploit opportunities provided by the domestic market and global industry, and creatively foster the combination of existing capability and development of new capability.

#### *Limitation of this Study*

This study draws heavily on the experience of Chinese firms in two high-tech industries within the context of rapid economic development in a populous nation. Thus, there are limitations in generalizing conclusions from this study.

On the country level analysis, China is a unique case in international economic development. It has a large market and a strong government. It builds an open economy in the age of globalization. And the country has a deep manufacturing base developed in both the pre-reform era and the export-driven growth period. Nevertheless, some of these elements of Chinese development might emerge in other emerging economies.

There are several developing countries with large internal market, including India, Brazil, and Southeast Asia nations. Their markets might not be as large as China, but they could still create sufficient spaces and layers to allow indigenous business firms to develop advantageous knowledge and capabilities to access local markets. Local firms from these economies thus have a chance to leverage from local market access capabilities to create competitive advantages and build up innovation capabilities through collaborations with the global industry.

Since the world is experiencing de-globalization with rising trade barriers since the financial crisis in 2008-09, there are concerns that whether developing countries can still rely on globalization to grow. The contribution of trade to global GDP growth has been declining, and many industrialized nations are experiencing re-industrialization by moving production back to closer to the consumers. Emerging technologies such as 3D printing and distributed manufacturing are accelerating this trend. The result is that an export-driven growth model is increasingly difficult for developing countries to pursue. On the other hand, there is no evidence that the critical infrastructure of the global industry such as semiconductor and information technology industries would stop operating at the global scale, given that economy of scale matters in the key components such as production of semiconductor chips and R&D of algorithms. In such a world, an innovation strategy based on targeting domestic market and leveraging resources from global industry still make sense.

On the firm and industry level analysis, a limitation of this study is that the two industries examined are both industries with rapid technological changes and are organized in highly globalized and fragmented production system. There are concerns whether the experience of the two industries can be generalized.

However, it can be argued that these dynamic and globalized industries present the most difficult cases for innovation policies and strategies. In the mature industries, such as automobile, technological changes occur slow and production is geographically concentrated. Following the established learning sequence of reversed product cycle might be sufficient to accumulate and develop capabilities. In the emerging technologies, such as nanotechnologies, technological changes occur rapidly but a global production system is yet to develop. A nation might be able to nurture a relatively independent, emerging industry by establishing a full supply chain at home.

After all, if a nation can succeed in the most dynamic and globalized industries with highest entry barriers, there is no reason that it cannot succeed in economic development and innovation.

## APPENDIX. LIST OF INTERVIEWEES

No.	Name	Position	Organization	Location	Interview date
1	Yun Zhang	Researcher	CAS Institute of semiconductor	Beijing	5/24/2012
2	Dejun Jiang	Analyst	Private equity firm	Beijing	5/25/2012
3	Xudong Gao	Professor	Tsinghua University	Beijing	5/28/2012
4	Xielin Liu	Professor	CAS Graduate school of management	Beijing	5/28/2012
5	Tao Wu	Assistant Chairman	Jie Chen Shine Technology Corp	Beijing	5/28/2012
6	Wei Hu	Chief strategist	Sinovel Wind Group Co. Ltd	Beijing	5/29/2012
7	Xuezhao Zhang	Senior Project Manager	Sinovel Wind Group Co. Ltd	Beijing	5/29/2012
8	Zhang	Planning manager	Beijing New Energy Automobile Co.	Beijing	5/29/2012
9	Yahui Liu	Sales manager	Beijing Pride Power System Technology Co.	Beijing	5/30/2012
10	Stuart Emmons	PR manager	Goldwind	Beijing	5/30/2012
11	Jiang Yu	Professor	CAS Institute of policy and management	Beijing	6/5/2012
12	Feng Lu	Professor, Director at Institute for Government and Enterprise	Peking University School of Government	Beijing	6/6/2012
13	Xuezhao Zhang	Senior Project Manager	Sinovel Wind Group Co. Ltd	Beijing	6/7/2012
14	Shiuh-Wuu Lee	Vice President of Technology Research & Development	Semiconductor Manufacturing International Corp.	Shanghai	6/18/2012
15	Xiaowei Gu	Manager	IC Café	Shanghai	6/19/2012
16	Dai Guan	Director	Shanghai Testrong Technologies	Shanghai	6/19/2012
17	Shen Wu	Marketing manager	Shanghai Electric	Shanghai	6/20/2012
18	Gang Li	Founder	Memsensing	Suzhou	6/30/2012
19	Renhong Su	Director	Walden International	Suzhou	6/30/2012
20	Zhifeng Xie	Former Senior Director	Semiconductor Manufacturing International Corp.	Suzhou	6/30/2012
21	Rucheng Wang	Journalist	First Economics and Finance Daily	Shanghai	7/3/2012
22	Yaxi Han	Director of R&D	Trina Solar	Shanghai	7/5/2012
23	Yunwang Hu	Senior headhunter	KT Human Resource	Shanghai	7/5/2012
24	Shuang Wang	Senior Analyst	China Photovoltaic Industry Alliance	Nanjing	7/11/2012
25	Hongli Wang	R&D Manager	Zhongshen Group	Nanjing	7/17/2012
26	Renbao Sun	Assistant to President	China Sunergy	Nanjing	7/18/2012
27	Jun Lu	Deputy Director of R&D	China Sunergy	Nanjing	7/18/2012
28	Yaozong Bai	Deputy General Manager	Sinoma Science & Technology Co.	Nanjing	7/18/2012
29	Mingjun Wu	Deputy President, R&D Division	Nanjing Highspeed & Accurate Gears	Nanjing	7/19/2012
30	Xia Cai	Vice President, R&D division	Guodian Nanjing Automation Co. Ltd	Nanjing	7/19/2012
31	Huaming Zhu	Deputy General Manager	Wiscon System Co.	Nanjing	7/20/2012
32	Xiaoyan Gao	Manager	XinCheJian Maker Space	Shanghai	8/2/2014

33	Yuxiang Zhou	Engineer	HiSilicon	Shanghai	8/2/2014
34	Huiming Zhou	Manager	Tongji University Maker Space	Shanghai	8/4/2014
35	Daniel Zhang	Vice President	Huawei Technologies	Shenzhen	8/11/2014
36	Joseph Smith	Key Programs Executive	Huawei Technologies	Shenzhen	8/11/2014
37	Haibo Lin	Vice President	Huawei Technologies	Shenzhen	8/12/2014
38	Charles Ai	VP; Head of Early Stage Investment, R&D	Huawei Technologies	Shenzhen	8/12/2014
39	Linlin Hou	Board of Directors' Secretariat	Huawei Technologies	Shenzhen	8/12/2014
40	Xishen Jiang	Senior VP	Huawei Technologies	Shenzhen	8/12/2014
41	Haihua Guo	Director	Huawei Technologies	Shenzhen	8/12/2014
42	Yongbo Xue	Director	Huawei Technologies	Shenzhen	8/12/2014
43	Amy Lin	Vice President	Huawei Technologies	Shenzhen	8/13/2014
44	Mengbin Wen	Director	Huawei Technologies	Shenzhen	8/13/2014
45	Xin Tong	Professor of Geography	Peking University	Beijing	8/15/2014
46	Sheng Wang	PR Director	Huawei Technologies	Shenzhen	7/7/2015
47	David Wang	Director of Standard and IPR Strategy	Huawei Technologies	Shenzhen	7/8/2015
48	Xiangbin Li	Senior engineer	Huawei Technologies	Shenzhen	7/8/2015
49	Qi Li	Vice president for wireless business	Huawei Technologies	Shenzhen	7/9/2015
50	Yong Peng	Director	Huawei Technologies	Shenzhen	7/10/2015
51	Ke Li	Vice President	Huawei Technologies	Shenzhen	7/14/2015
52	Xiangbin Li	Senior engineer	Huawei Technologies	Shenzhen	7/14/2015
53	Ricky Lee	Professor and Dean	HKUST Shenzhen Institute	Shenzhen	5/18/2016
54	Bin Yu	Factory director	Huawei Technologies	Shenzhen	4/11/2017

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